ASTRONOMY

April 1984
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Superclusters

Stars Too Small to Burn

Hunting for Pluto

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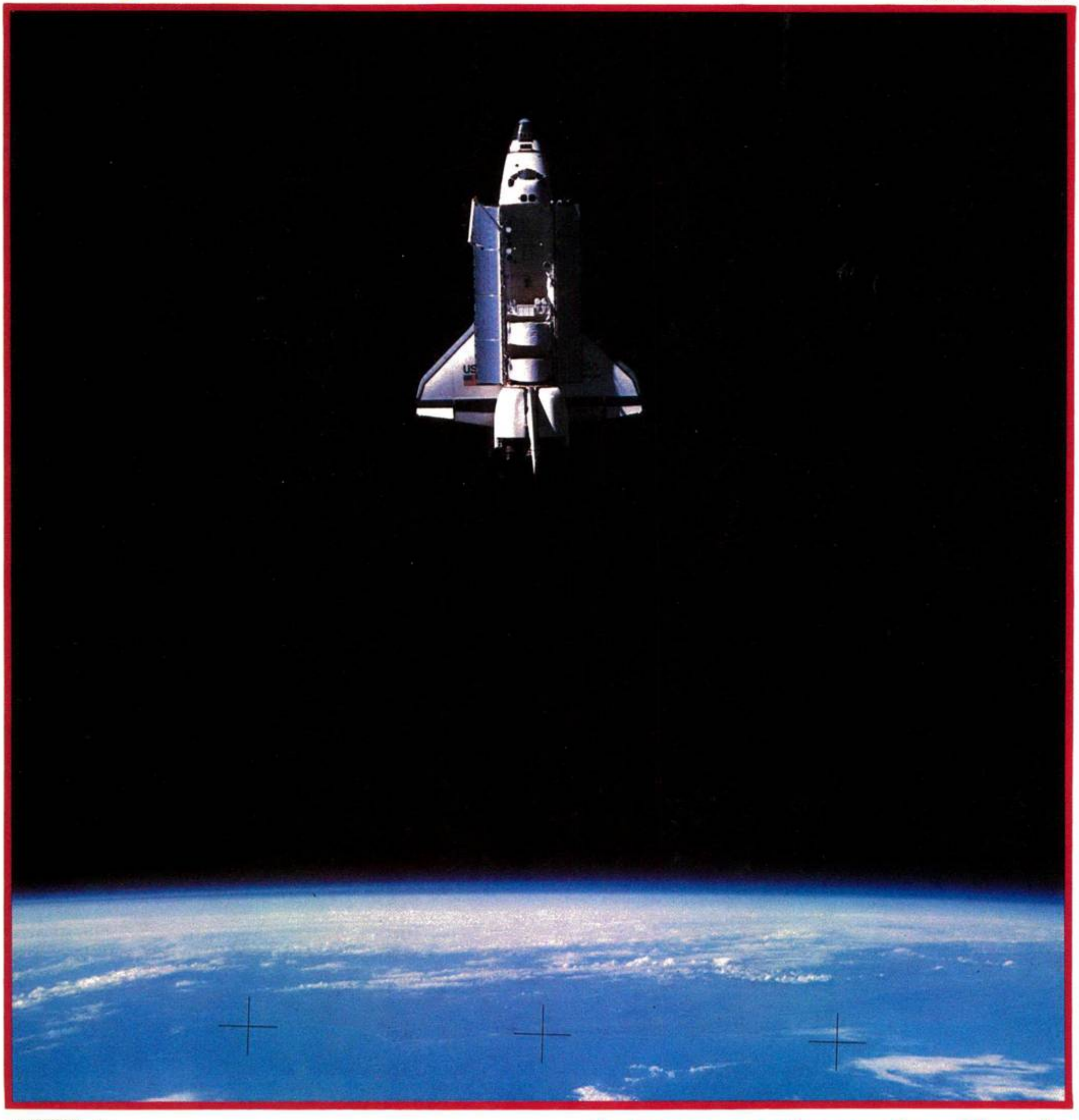
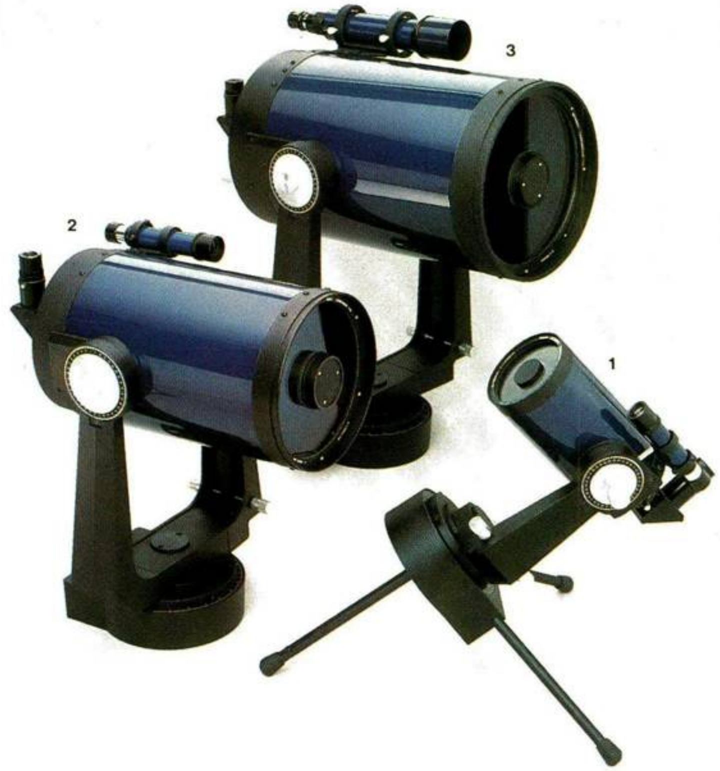
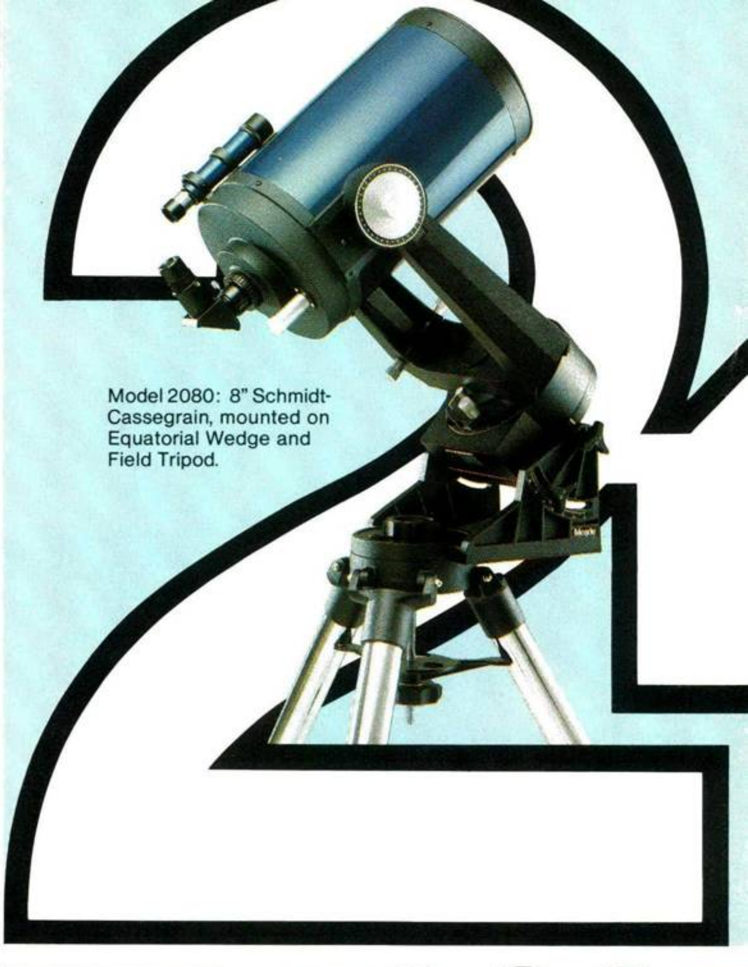


Astronomy from the Shuttle

Meade Schmidt-Cassegrain Telescopes: **(1)** 4" Model 2044, with standard-equipment table tripod; **(2)** 8" Model 2080; **(3)** 10" Model 2120.





Model 2080: 8" Schmidt-Cassegrain, mounted on Equatorial Wedge and Field Tripod.

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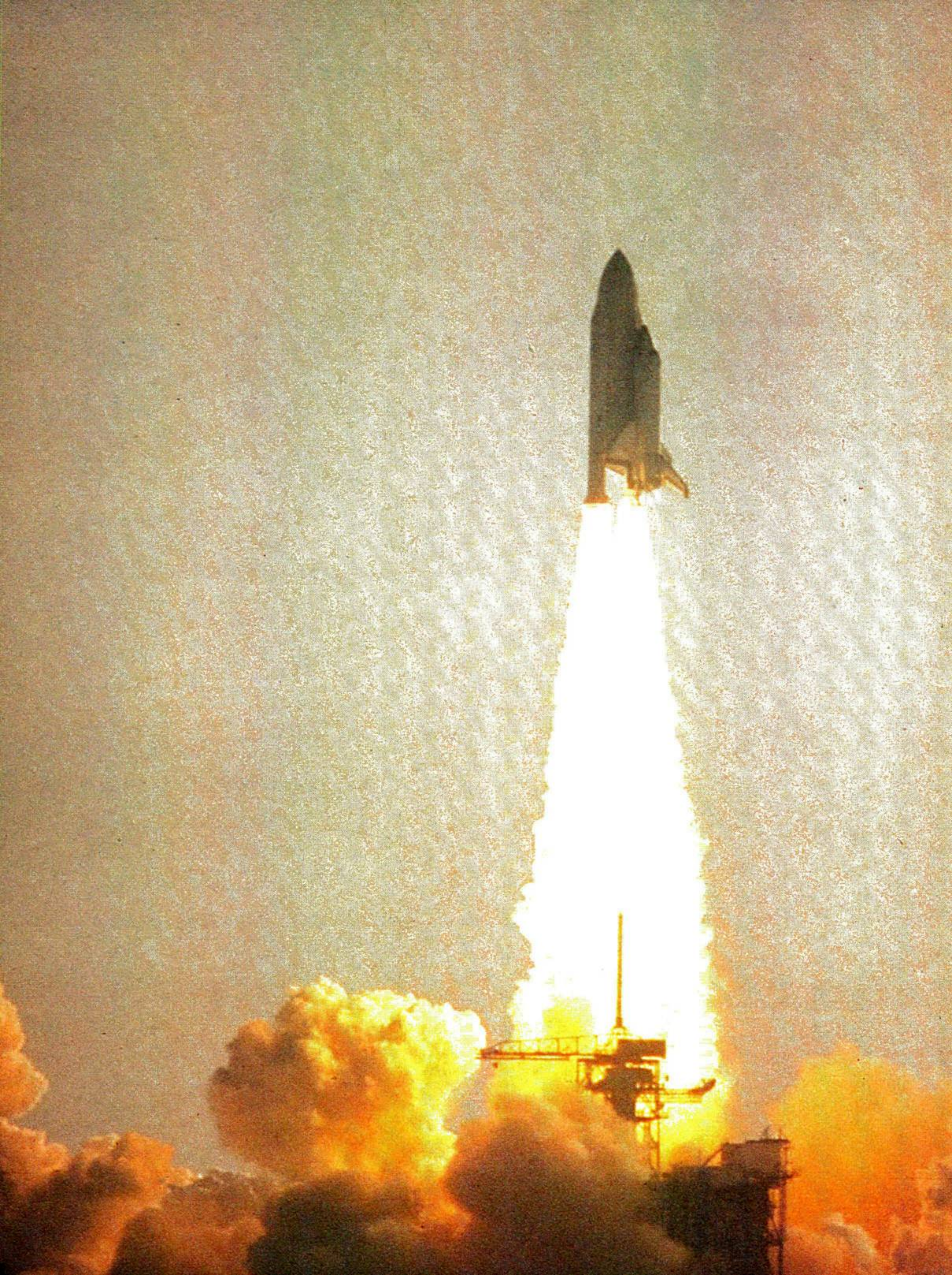

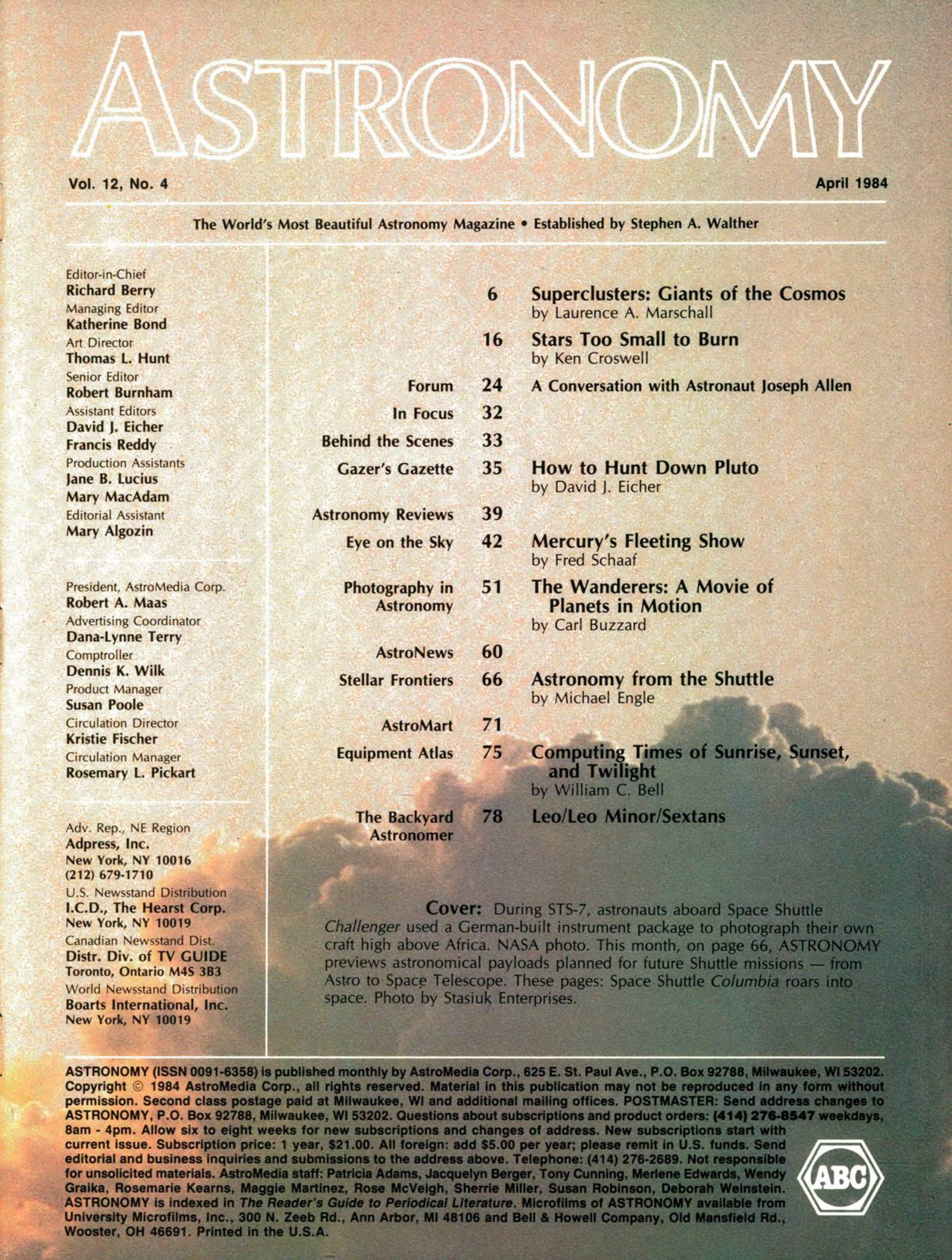

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Cover: During STS-7, astronauts aboard Space Shuttle *Challenger* used a German-built instrument package to photograph their own craft high above Africa. NASA photo. This month, on page 66, ASTRONOMY previews astronomical payloads planned for future Shuttle missions — from Astro to Space Telescope. These pages: Space Shuttle *Columbia* roars into space. Photo by Stasiuk Enterprises.

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SUPERCLUSTERS:

Great fleas have little fleas upon their backs to bite 'em,
And little fleas have lesser fleas, and so ad infinitum . . .
And the great fleas themselves, in turn, have greater fleas to go on;
While these in turn have greater still, and greater still, and so on . . .

— Augustus De Morgan
A Budget of Paradoxes

Giants of the Cosmos

by Laurence A. Marschall

These galaxies in the constellation Leo form a small, physically associated group. At sufficiently large scales, clusters of galaxies form superclusters — titanic structures shaped like flattened, twisted pancakes.

Hale Observatories

The world appears flat just a short distance away from our eyes. The simple visual cues that promote a sensation of depth — stereoscopic vision, relative size and motion, perspective — all vanish for objects more than a few hundreds of meters away. Though the universe stretches on, light-year after light-year, all we perceive of it is the two-dimensional tapestry of the sky — a pale, foreshortened image of the three-dimensional structure of the heavens. As seen by astronomers, the drama of the universe is like a play whose characters are visible only by the shadows they cast on a distant wall.

Thus the most basic questions — how is matter distributed in the universe? how big are the biggest things we can see? — are also the most difficult. To map the universe we must know the distances to objects within it; the greater those distances, the more uncertain and time-consuming are the methods needed to measure them. (See "How Far the Stars," ASTRONOMY, June 1983.) Consequently, only in recent years have astronomers been able to detect some of the large-scale structure of the world around us. As our perspective sharpens, we can begin to make out vague forms belonging to objects of truly cosmic proportions — superclusters of galaxies. Not surprisingly, great puzzles have appeared at the same time, problems that relate to the very foundations of the cosmic order. The excitement of discovery is tempered with perplexity.

To understand these new developments, consider first the fundamental problem of the measurement of distance. How have we been able to get around the limitations of our two-dimensional perception of the universe? For nearby objects, the task is relatively straightforward — the distance to the planets, for instance, can be determined with radar techniques. Scientists simply record the round-trip travel time of radio or light signals bounced off a planetary surface. Then, knowing the speed of light (around 300,000 kilometers per second), they can calculate the distance to the planet.

Outside our solar system, however, these methods fail, simply because of the vast spaces separating stars. If we could detect radar echoes from even the nearest star, the signal would take over eight years to return to Earth; for more distant stars, centuries would elapse. Instead, astronomers employ trigonometric methods, similar to those used by terrestrial surveyors, to pin down stellar distances. They photograph a star over half-year intervals to determine its apparent change in position against the background between exposures, a response to Earth's orbital motion around the Sun. The size of this so-called parallax shift, measured in fractions of a second of arc, is an indication of the star's distance.

But even with the aid of trigonometric parallax, astronomers remain frustratingly myopic. Stars beyond a few hundred light-years, scarcely beyond our own front yard on a cosmic scale, move less than a hair's breadth on photographs taken six months apart. For objects beyond this — that is, for most of the stuff in the universe — a host of methods less trustworthy than either radar or trigonometry must be employed.

Most of these techniques involve an estimate of how much the light we see has dimmed between its source and our eyes. For many stars, light output (or intrinsic luminosity) can be determined simply by looking at the overall features of the star's spectrum. For stars that vary in light output, such as RR Lyrae and Cepheid variables, the intrinsic luminosity can be estimated by the length of time the star takes to go through one cycle of dimming and brightening. Then by comparing the estimated luminosity of a star with the actual amount of light we receive (its observed brightness), we can estimate the distance of a star with some confidence.

Surprisingly, some of the brightest stars in the sky (for instance Rigel, in the constellation of Orion) are also very distant; they appear bright because they emit a great deal of energy. The majority of the stars near the Sun, and presumably the majority of stars in space, are not very luminous, and hence appear faint even when they are close by. At a distance of 50 light-years, our own Sun would scarcely be visible to the naked eye.

These methods of determining distance by comparing luminosity and brightness, along with other refined methods of optical and radio astronomy developed over the last decades, have led to a sophisticated and striking image of the star system we live in. When we see the glowing band of the Milky Way against the dark night sky, most of us can now recognize it for what it is: a cross-section of a huge spiral galaxy, a pinwheel of stars over a hundred thousand light-years in extent, containing the mass of a hundred billion suns.

Although galaxies like our own are scattered throughout the universe, it is difficult to study individual stars of known luminosity in systems *outside* the Milky Way. How are the galaxies arranged? Do they form distinctive patterns like the pinwheels of stars in our Galaxy? Or are they scattered at random, like grains of sand on a beach?

Even without knowing the exact distance of the galaxies, it is clear that they are not distributed evenly in space. In certain directions in the sky, bright spiral galaxies seem to cluster together. A brief glance at a detailed sky atlas reveals rich groupings of galaxies in the directions of the constellations Virgo, Coma Berenices, and Perseus. Early scientific studies of the distribution of galaxies, such as those carried out by Harvard astronomer Harlow Shapley, identified many such clusters in the sky, culminating in the 1950s with the work of George Abell, who catalogued over 2,500 galaxy clusters on survey photographs of the heavens.

Our own Milky Way Galaxy is itself a member of a cluster of galaxies — the "Local Group," as astronomers call it. Because we are embedded in it, the Local Group is more difficult to recognize than the great cluster in Virgo. It was only when the actual distances of galaxies were measured (by estimating the luminosities of stars in them) that several dozen, including the Magellanic Clouds, the Great Galaxy in Andromeda, M-33, and numerous dwarf galaxies, were found to be close neighbors of ours.

The Local Group is a small and sparsely populated cluster, containing only a few dozen members. Rich clusters of galaxies, like the one in Virgo, contain hundreds or thousands of galaxies of all types. These rich clusters invariably contain near their center one or two of the largest types of galaxies known — giant elliptical galaxies, which may contain as much material as 50 spiral galaxies like our Milky Way. Some giant ellipticals near the centers of rich clusters of galaxies are cannibals, feeding on the stars of nearby spiral galaxies, and growing as they engulf and incorporate other members of the cluster.

To study the really large-scale structure of the universe, however, we must rely on more than just the appearance of galaxies on the celestial sphere. Experience with stars in our own Galaxy teaches us that it is possible to mistake chance superpositions of distant and nearby stars for real physical structures. The Pleiades are indeed a single cluster of stars, but most constellations contain stars that just happen to line up from our earthly vantage point. Bellatrix and Betelgeuse in Orion's shoulders, for instance, lie several hundred light-years nearer to us than the rest of the stars in his body.

Some astronomers, notably James Peebles at Princeton University, have attempted to apply statistical methods to analyzing the distribution of galaxies on the celestial sphere without considering distance. While a large-scale randomness appears in these studies, with just a hint of the presence of giant structures, it is difficult to determine the details of the distribution with any great confidence. The most straightforward and intelligible way to learn about the universe-at-large is simply to plot the precise positions of galaxies in three dimensions. For this, we must know the distances of thousands of galaxies so that the overall distribution will stand out.

But finding the positions of distant clusters of galaxies is a formidable task. While it is possible to single out individual stars in members of the Local Group, and thus derive distances by the methods used for finding distances in our own Galaxy, it is difficult or impossible to do so for more remote galaxies. Single stars can no longer be resolved at great distances; the feeble light that reaches us from them is too weak for easy analysis. Only the collective light from an entire galaxy will suffice.

A powerful method of finding distances to galaxies was developed by pioneer cosmologist Edwin Hubble in the late 1920s. Observing the spectra of galaxies, he noticed patterns of dark lines similar to those produced by absorbing atoms in the outer layers of stars in our own Galaxy. The wavelengths of these lines had been well determined by observing the absorption of light by gases, like calcium and magnesium vapors, in laboratories on Earth.

The wavelengths of the dark absorption lines measured in galaxies, however, were all longer (redder) than those determined on Earth. Hubble explained this lengthening, or "redshift," as due to the motion of the distant galaxy away from the Sun and the well-known phenomenon called the Doppler effect. What was exciting, however, was that the farther the galaxy, the greater was the redshift of its spectral lines. The galaxies seemed to be speeding away from our own, as if driven by some aversion to the Milky Way, and the more distant galaxies were receding more rapidly.

We interpret this today as a result of the uniform expansion of space, the outward motion of the universe after a cosmic explosion about 15 billion years ago — the "Big Bang." The observed Doppler shift of a galaxy is proportional to its distance. For instance a galaxy at a distance of ten million light-years is moving away with a speed of about 250 kilometers a second, while one 10 times farther away moves at 2,500 kilometers per second.

This neat relationship provides astronomers with a powerful method for determining the distance of a galaxy. First, astronomers obtain a spectrum of the galaxy; they then compare the wavelengths of spectral lines in the galaxy with laboratory values to find the velocity of recession, and Hubble's relation gives us the distance. At last, we can begin to plot a three-dimensional map of the heavens.

Easier said than done! Although 50 years have passed since Hubble first proposed it, we are only now beginning to develop that full-scale picture of our universe. The prime difficulty is the feebleness of the light from distant galaxies. In Hubble's time it might have taken a day or more of continuous exposure (spread over several nights' observing) to produce a photograph of a galactic spectrum. To survey even a tiny fraction of the billions of galaxies in the universe would have occupied the lives of hundreds of generations of astronomers.

But times change — along with larger telescopes, we now have a host of new light detecting and intensifying devices that make the wholesale determination of the distances to other galaxies a reality at long last. With today's charge-coupled detectors, image intensifiers, and digital computers, obtaining and analyzing the spectra of a galaxy takes minutes, instead of hours. There are even devices that use optical fibers to feed the light from several dozen galaxies to a single spectrograph for simultaneous recording. (One is named "Medusa" after the many light pipes snaking into its entrance aperture.)

In short, only recently have many galactic distances become available to astronomers. A major catalog of redshifts, compiled during the 1970s by astronomers at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, contains measurements out to several hundred million light-years from the Milky Way. Even deeper studies of small regions of the sky have been carried out by researchers at several other locations. When the positions of galaxies are plotted in three dimensions, a fresh and exciting picture of the universe emerges.

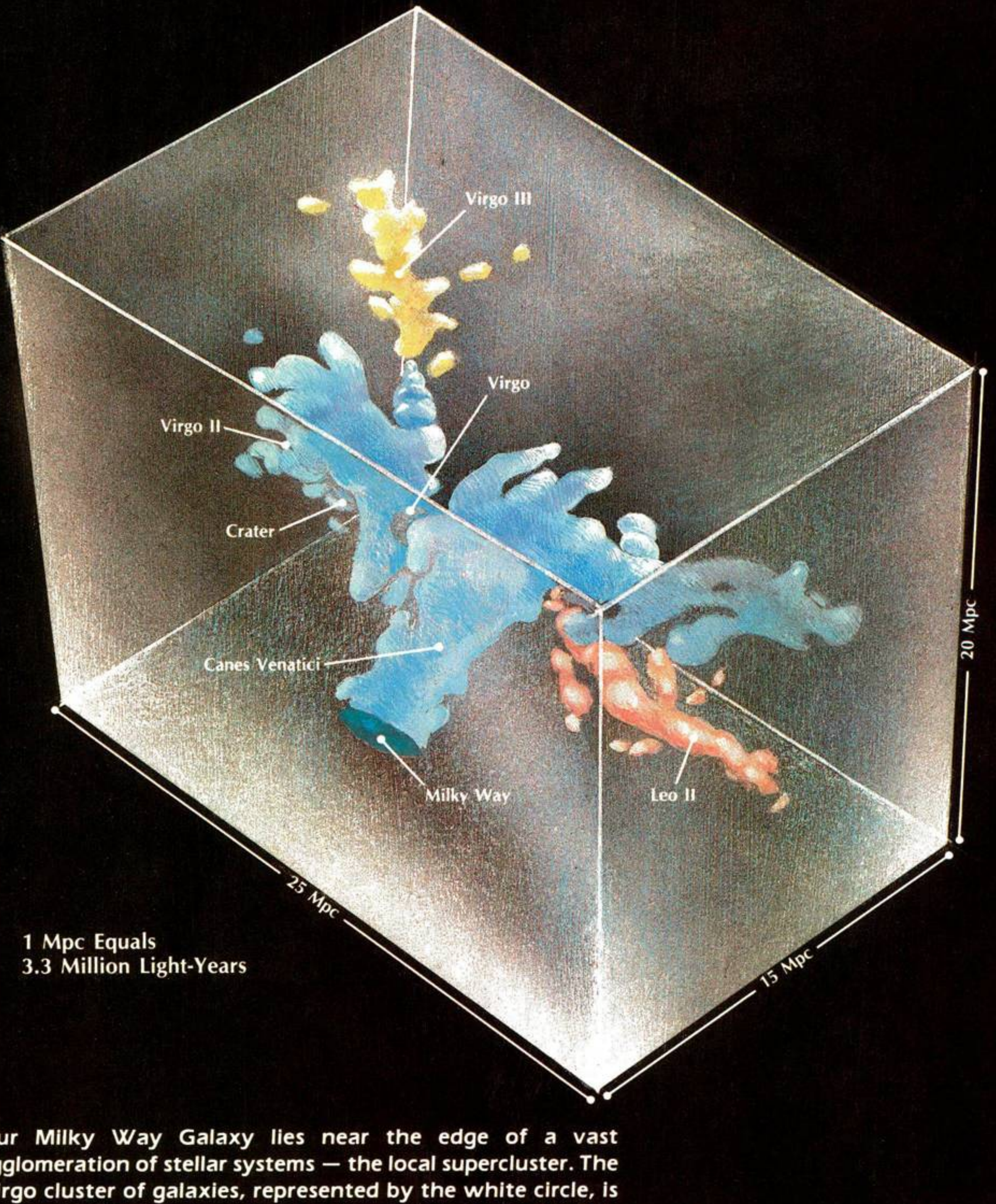
Figuring prominently in this new cosmic portrait are gigantic strands of galaxies, called superclusters for want of a better term. These are immense, elongated objects that stretch several hundred light-years through space. They appear as stringlike filaments snaking through the universe, though studies of the nearer galaxies suggest that they are shaped more like twisted pancakes than strands of spaghetti. The cosmos is a tangled skein of these superclusters.

The picture is actually even more complex: Superclusters, it seems, do not form a single tightly twisted mass — there is mounting evidence that huge gaps lie between them. In the direction of the constellation Bootes, for instance, Robert Kirshner of the University of Michigan, Augustus Oemler of Yale, Paul Schechter of the Center for Astrophysics, and Stephen Schectman of Mount Wilson Observatory have found evidence of a void between superclusters over 250 million light-years in diameter. As far as these researchers can determine, there are *no* galaxies at all in this region. Imagine — well over a billion Milky Ways could fit into a volume this large!

Yet this void seems to be fairly typical. Other studies have confirmed the presence of mammoth empty spaces in several other directions. Astronomers estimate that the tangled strands of the superclusters may occupy no more than five percent of the volume of the universe. The rest may be virtually empty.

In our vicinity, of course, space is far from empty, for we live in a typical supercluster — a huge agglomeration that includes our own Local Group of galaxies as well as the giant Virgo cluster. The University of Texas astronomer Gerard de Vaucouleurs has argued for the presence of such a Local Supercluster since the 1950s. The evidence was at first only suggestive, but many astronomers now regard it as compelling.

The Local Supercluster


Virgo III
Virgo
Virgo II
Crater
Canes Venatici
Milky Way
Leo II
20 Mpc
25 Mpc
15 Mpc

1 Mpc Equals
3.3 Million Light-Years

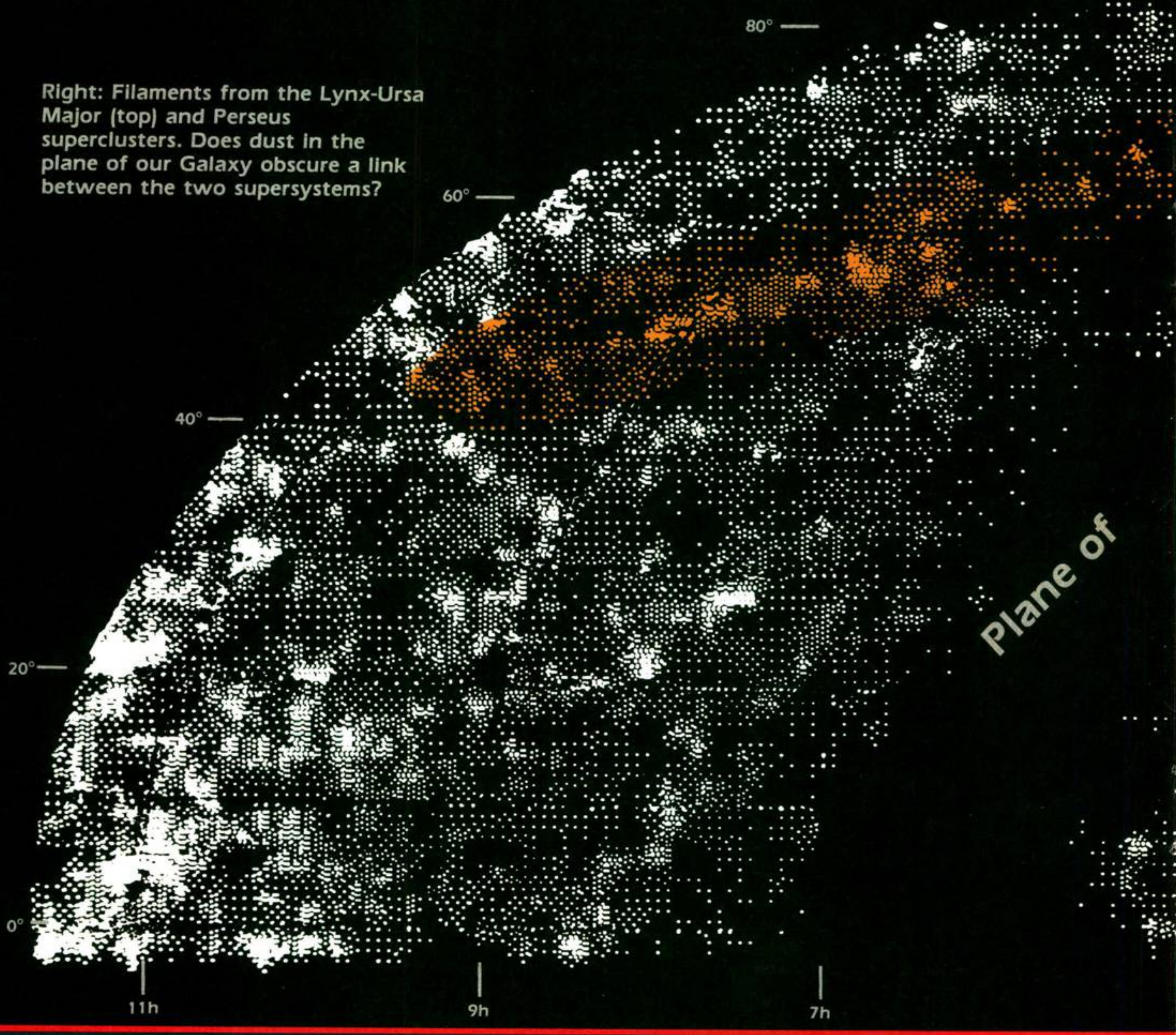
Our Milky Way Galaxy lies near the edge of a vast agglomeration of stellar systems — the local supercluster. The Virgo cluster of galaxies, represented by the white circle, is the center of the supersystem and contains 20 percent of its bright galaxies. The Virgo II and Canes Venatici clouds together hold another 40 percent of the supercluster's galaxies. The remaining 40 percent reside in a few clouds of galaxies that surround the main system. The total volume of the cube shown here is 7,500 cubic megaparsecs — nearly 260 billion cubic light-years!

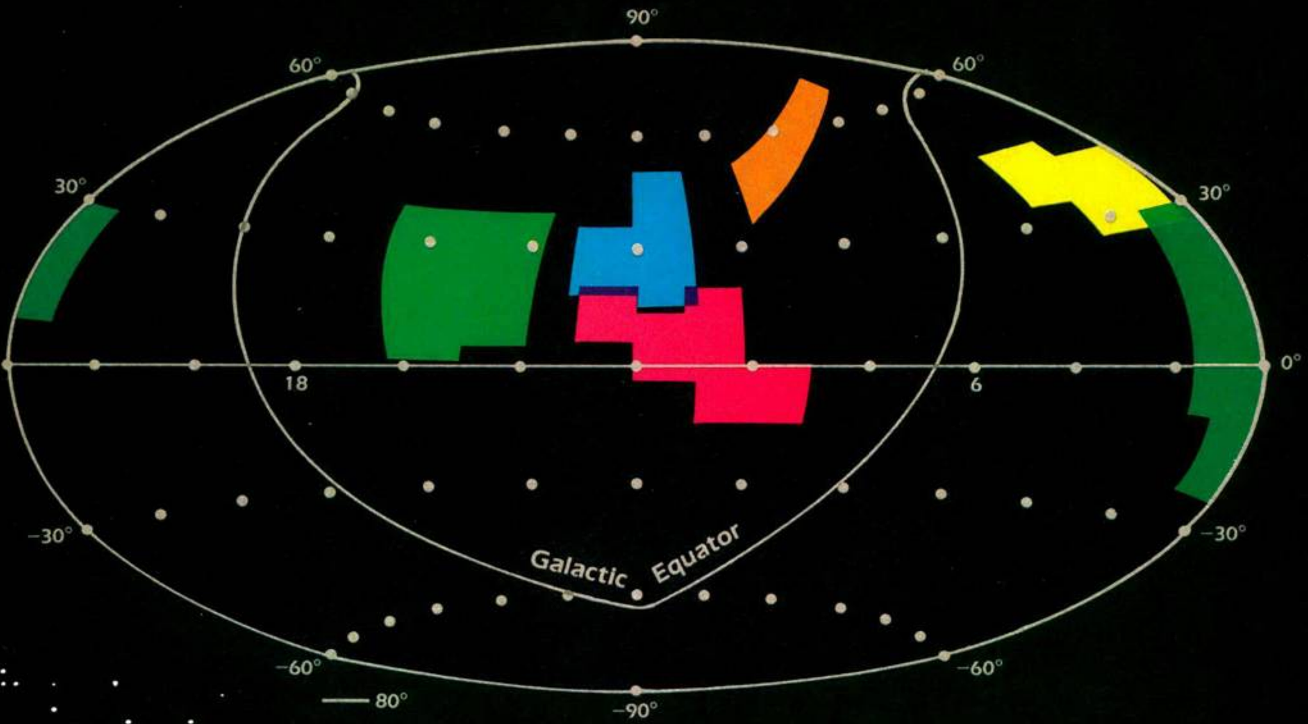
Known Superclusters

Name	Largest Dimension (Millions of Light-Years)	Distance to Center (Millions of Light-Years)
Perseus	225	200
Lynx-Ursa Major	200	200
Coma (with possible extension)	261	345
Hercules (with possible extension)	650	730
Pisces-Cetus (possible supercluster)	650	590
Sextans-Leo (possible supercluster)	650	815

Data for extensions and new superclusters from Jack Burns and David Batuski, University of New Mexico.

Right: Filaments from the Lynx-Ursa Major (top) and Perseus superclusters. Does dust in the plane of our Galaxy obscure a link between the two supersystems?

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Galactic Equator
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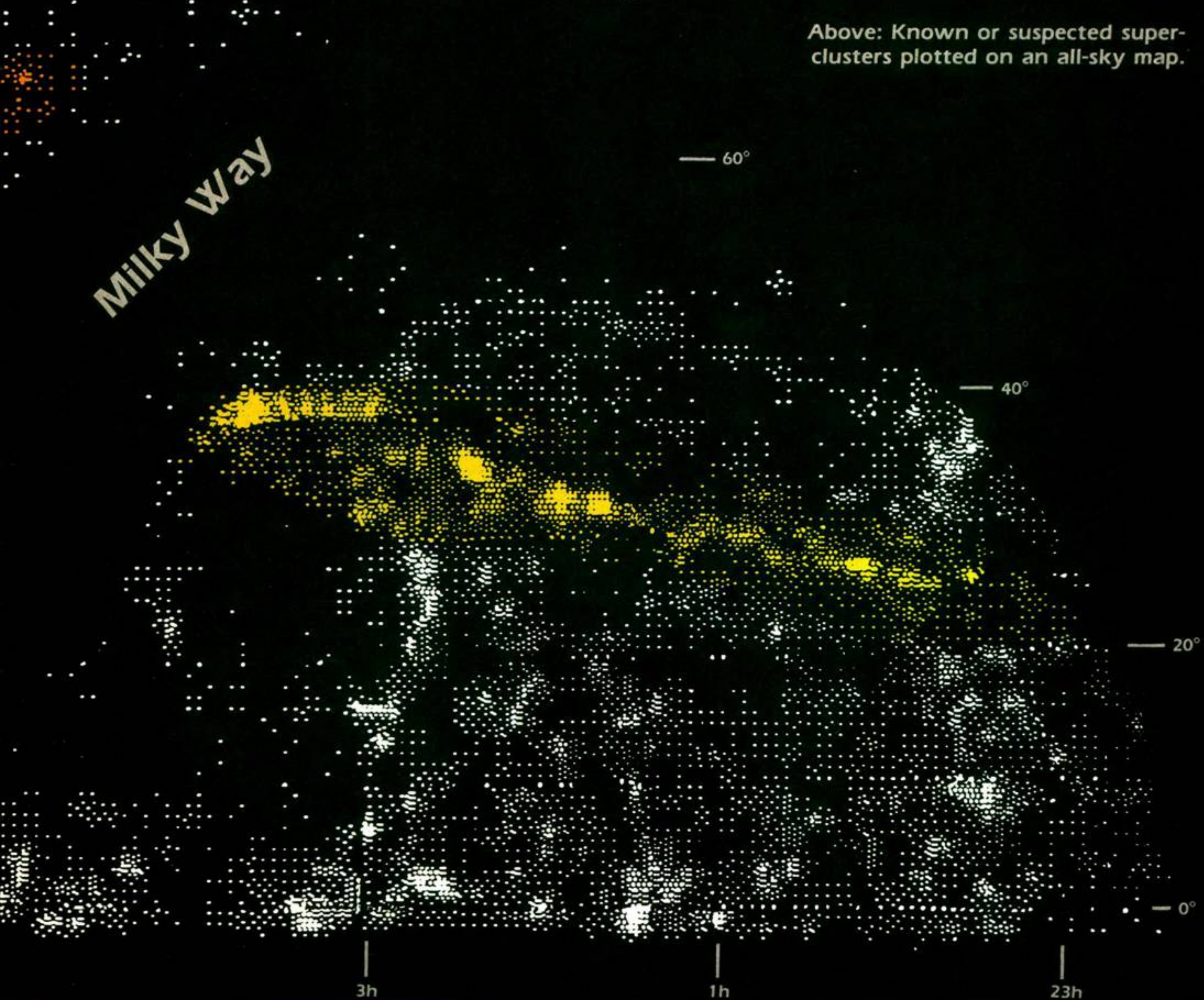
Above: Known or suspected superclusters plotted on an all-sky map.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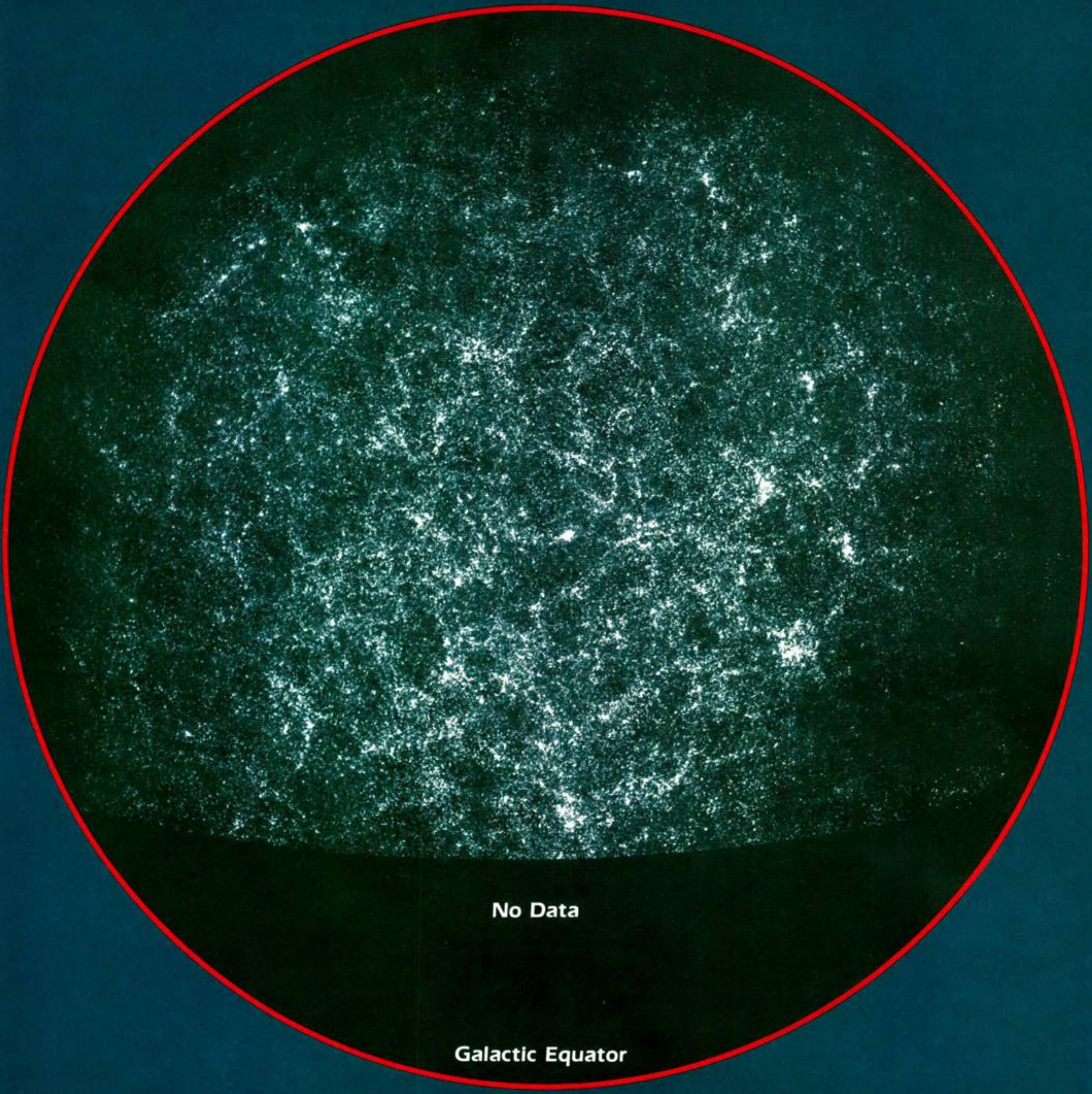
Skein of the Universe



Delicate filamentary structures emerge in this plot of about one million galaxies, each represented by a single picture element. At the map's center is the north galactic pole; the circle represents the galactic equator. Map by M. Seldner, B.L. Siebers, E.J. Groth, and P.J.E. Peebles, from Lick Observatory.

Many more bright galaxies lie in the northern hemisphere of the sky, since the main body of the Local Supercluster lies to the north of us. It appears to be a flattened pancake of galaxies, with several large clusters, like Virgo, appearing as concentrations in the overall distribution; filling in the spaces between the large clusters are smaller groupings, like our own Local Group of galaxies. The large clusters are like knots in a tangled mass of yarn, with thinner strands — composed of single galaxies and small clusters of galaxies — snaking between them. The Local Supercluster is about 100 million light-years long, but only about 10 million light-years thick.

Although our Local Supercluster is typical of the several superclusters that have been discovered so far, it is by no means the largest. That honor belongs to a vast assemblage of matter discovered by astronomers Martha Haynes and Riccardo Giovanelli using radio telescopes at Green Bank, West Virginia, and Arecibo, Puerto Rico. Haynes and Giovanelli were searching for superclusters by looking at the redshifts of 21-centimeter radio waves emitted by clouds of hydrogen atoms in galaxies. In the direction of the constellations Lynx and Ursa Major they discovered a string of galaxies, all at a distance of about 200 million light-years, stretching over 40 degrees across the sky. The Lynx-Ursa Major supercluster was previously unknown, but more exciting still, this string of galaxies seemed to line up with an already recognized supercluster in the constellations Pisces and Perseus. Suggestively, the Pisces-Perseus supercluster lay at the same distance of 200 million light-years.

The two strings of galaxies were separated by a gap about 20 degrees wide, through which runs the plane of our own Milky Way. This region, long known to astronomers as the "zone of avoidance," is notably devoid of galaxies, simply because obscuring gas and dust in the plane of our Galaxy block out the light from the more distant objects outside. Haynes and Giovanelli concluded that the Lynx-Ursa Major supercluster and the Pisces-Perseus supercluster were one and the same. If they are correct, the Pisces-to-Ursa Major supercluster spans half the sky and extends over 700 million light-years through space. It is truly a behemoth.

We can scarcely grasp the enormous scale of this emerging view of the cosmos. Our solar system rests in a galaxy of a hundred billion suns, a spiral galaxy so large that radio waves reaching us from its center began their journey before the dawn of recorded history. But our Galaxy is small stuff. It is one of a dozen members of a local cluster, several million light-years across. And even here we are still talking small — the superclusters are strings and sheets of clusters over 50 times larger. The clusters of galaxies are only bit players in the overall drama.

It is possible that there may be structures in the universe even larger than the superclusters, but current cosmological ideas suggest that we may finally have discovered the biggest things there are to find. A universe of superclusters separated by enormous voids seems to be a natural outcome of the Big Bang scenario as it is understood today (see "Cosmology on a Computer," ASTRONOMY, June 1983).

According to the Big-Bang theory, the universe began expanding from a dense, high-temperature state about 10 to 15 billion years ago. Temperatures ranged in the billions of degrees during the first minutes of creation. At that time, space was filled with high-energy nuclear particles and intense radiation, all moving about in a random and chaotic fashion. Because everything was packed so densely, space was opaque; light could travel only a short distance before it encountered a particle of matter and was deflected or absorbed.

This constant interaction of nuclear particles with photons (particles of electromagnetic radiation, of which light is just one type) insured the preservation of a state of primeval chaos. From time to time random fluctuations in the density of matter occurred, regions where material was just a bit more concentrated than in other regions — just as we see thin spots and dense spots in a mass of turbulent thunderclouds. But because of the high temperatures and intense radiation fields of the early universe, all but the largest of these density fluctuations dissipated just as quickly as they were born. The universe in its early state was remarkably uniform.

As the universe expanded, however, it cooled; after several hundred thousand years its temperature dropped to a point where matter and energy ceased to interact strongly with one another. Radiation, which had played a major role in smoothing out the density fluctuations in the early universe, now traveled unimpeded through the thinning reaches of the cosmos. Since space had become transparent at this time, we should be able to detect radiation from this era. We see it as the low-energy background radiation that bathes us in a constant stream of microwaves.

According to the model, some large-scale fluctuations in the density of matter remained at the time the universe became transparent. Though the details vary, it seems likely that the dense blobs of material generated in the cooling universe contained the mass of a thousand trillion to 10 thousand trillion suns — about the size of a typical supercluster of galaxies. Because these supercluster-size blobs contained more matter than the surrounding space, they may have collapsed under their own mass to form clusters of galaxies and individual stars shortly after this time. Indeed some versions of the density-fluctuation model even predict the formation of supercluster pancakes and strings much like those actually observed by astronomers.

Much of this work is highly tentative, for the theoretical underpinnings of cosmology are still rather shaky. The details of the supercluster formation process depend critically on our understanding of the behavior of the fundamental forces of nature and on the interaction of the tiny particles, such as quarks and neutrinos, that constitute matter.

But this need not discourage us. We may at last have discerned the largest objects in the universe; there may be no "bigger fleas," contrary to what the logician De Morgan claimed. Yet the search for a complete understanding of the structural framework of the universe is just beginning. We have mapped only a short pace outward toward the limits of the universe. The Space Telescope, with the ability to penetrate several times farther and several times fainter, should change these figures significantly in just a few years. For those who would understand the largest structures in existence, there are exciting times ahead.

Laurence Marschall is associate professor of physics at Gettysburg College and director of its observatory and planetarium. His research interests center on proper motions in young open clusters. His last article for ASTRONOMY was "Galactic Coronas" in the November 1982 issue.

STARS TOO SMALL TO BURN

by
Ken Croswell

Just a few light-years from our solar system lies a cold, dark, invisible object. Only a twentieth of the Sun's mass, it still retains the small planetary system that was born with it. But these planets whirl about their sun in darkness, for the star does not shine. Any light that touches their chill surfaces comes from other stars, like Sirius, Alpha Centauri, or our own Sun.

This dark star is neither a black hole nor a neutron star. It is a black dwarf — a star so small its core never grew hot enough to ignite. Although virtually undetectable from Earth, black dwarfs may swarm through our Galaxy and others in uncountable billions — and thereby mold the destiny of the entire universe.

Stars of all kinds are born in dusty gas clouds like the Orion and Lagoon Nebulae. Some of these have many times the Sun's mass, while others are smaller; the nebula's temperature and density determine how large or small a given star will turn out to be. From studying conditions in these stellar nurseries, many astronomers have deduced that the minimum mass for a star is roughly a hundredth of a solar mass, or 0.01 $M_\odot$. At the same time, the laws of physics show that a star below a certain critical mass will never become hot enough to initiate thermonuclear fusion of hydrogen in its core. For young stars composed of solar-type material — a mix of hydrogen, helium, and many other elements — this critical mass is 0.085 $M_\odot$. For older stars made from a purer hydrogen/helium mix, it is slightly greater. But whatever its chemical content, a star below the critical mass can never tap its nuclear fuel. Yet these stars that are too small to burn can still shine, and astronomers can still see them — at least in principle.

To understand how, let's follow the life of a very-low-mass star from its birth in a typical nebula. The story begins with the gravitational collapse of the protostar's constituent masses — clouds of dusty gas. As the clouds collapse, the protostar converts some of its gravitational energy into thermal energy and warms up, becoming hot enough to glow dully. On the Hertzsprung-Russell diagram (see "Decoding the H-R Diagram," ASTRONOMY, October 1983), it lies far to the right and above the Main Sequence. As the star collapses, its surface area decreases, and its total luminosity drops. The star thus moves down on the H-R diagram toward the Main Sequence on a path called a Hayashi track, after the Japanese astronomer who first described this phase of stellar evolution.

Shortly afterward, the star becomes hot enough to "burn" deuterium in a fusion reaction. Deuterium is an isotope of hydrogen; its nucleus contains one proton and one neutron, whereas normal hydrogen nuclei have just a single proton. Deuterium fuses by capturing a proton and creating helium-3, an isotope of helium that consists of two protons and one neutron. (Normal helium has two protons and two neutrons.) But deuterium is the only form of hydrogen our midget star can burn, because deuterium's fusion temperature is low — normal stellar fusion reactions involving hydrogen require much higher temperatures. As deuterium burns, the radiation produced exerts a pressure on the overlying layers of the star that halts its gravitational collapse temporarily.

But deuterium is rare. Hydrogen is thousands of times more abundant, and so deuterium fusion lasts for only a few million years. When the supply runs out, the reaction ceases and the star resumes its collapse. The radius shrinks and the luminosity falls once again. As it did before, the star glows with the heat of gravitational contraction. More massive normal stars also start their lives on Hayashi tracks, which lead them to the Main Sequence, where they burn normal hydrogen into normal helium. Our very-low-mass star can't do that, however. It contracts more and more, and eventually its core temperature peaks — but at a value too low for its hydrogen to begin fusion. So instead of falling onto the Main Sequence on the H-R diagram, the star falls through it.

Then a strange and paradoxical thing happens: the temperature begins to *drop* as the star keeps contracting. This occurs due to a quantum effect. Physicists recognize two types of particles: fermions and bosons. Fermions include such well-known particles as electrons, neutrons, and protons. Photons, on the other hand, are bosons. Fermions and bosons exhibit strikingly different behavior when placed close together: identical fermions repel while identical bosons attract. (This repulsion between identical fermions has nothing to do with the electromagnetic repulsion between similarly charged particles.) Since the effect increases as particle mass decreases, it is important *only for the lightest fermions* — the electrons.

When our very-low-mass star started its life, it was

so large and its density so low that its electrons hardly "noticed" each other. But when the star contracted, its electrons became more and more crowded. As gravitation pushed the electrons ever closer together, it siphoned off thermal energy and used it to pack the electrons more tightly. With the star's thermal energy diverted, its temperature fell. When quantum effects like these predominate, the star is said to be partially degenerate. Such a star continues to contract until it becomes fully degenerate — when its electrons cannot be packed any closer. The result is a black dwarf with a radius of about one tenth the Sun's.

The degenerate black dwarf then cools, its heat slowly escaping into space over a period of several billion years. Even though the star is no longer burning fuel, the fermionic repulsion between the electrons supplies enough pressure to hold the entire star up against the inward pull of gravity. But any hope that the star might shine like its more massive siblings is gone. The star is, for all practical purposes, dead — beyond the reach of even the largest and most sensitive Earth-based telescopes.

Yet it takes hundreds of millions of years for the star to contract to the black dwarf state, during which time it glows feebly. Over most of this period, it appears in all respects to be an M-type red dwarf — and astronomers can detect these.

But how will they know? If astronomers find a star whose mass clearly lies below 0.085 $M_\odot$, they have a strong candidate. Unfortunately, determining the mass of a star is difficult and uncertain. As an example, consider the red dwarf binary Luyten 726-8, which lies just 8.4 light-years away. The fainter component of this double star system is the prototype flare star UV Ceti. Fifteen years ago astronomers believed each component's mass was only about 0.04 $M_\odot$ — well within the looked-for limit. But a 1973 redetermination revealed that each star's mass was nearly three times the older value.

The very nature of these subcritical mass stars poses problems. For a typical star on the lower Main Sequence, we can get a fairly accurate estimate of its mass from its absolute magnitude. But this method hardly works for subcritical stars, since they do not lie on the Main Sequence; moreover, a very-low-mass star also spends part of its life above the Main Sequence. In short, different rules probably apply, and estimating mass based on absolute magnitude is a risky affair.

Yet despite these problems, we do have some clues. For one thing, any very-low-mass star must be of type M and, additionally, will be very dim. Since these stars shine for only a few hundred million years after their birth, any we see must be quite young. Thus if we find a suspiciously dim red dwarf, we can eliminate it as a possibility if it exhibits other characteristics that mark it as an old star. One promising hunting ground for subcritical mass stars is a young star group like the Pleiades or the cluster associated with the Orion Nebula. The observational difficulties are formidable at present, but in years to come, the Space Telescope will probably uncover faint stars at large distances.

While stellar masses are hard to determine, absolute magnitudes are relatively easy — if only for the simple reason that until the Space Telescope is launched, any intrinsically faint star we find *must* be nearby in order to have been found at all. Since these stars lie so close, astronomers can get an accurate determination of their distances through straightforward trigonometric parallax. Knowing both the distance and apparent magnitude immediately yields the absolute magnitude.

For 40 years the intrinsically faintest star known was VB 10, discovered by George van Biesbroeck and often called van Biesbroeck's Star. VB 10 lies 18.8 light-years away and orbits the ninth-magnitude red dwarf BD +4° 4048. With an absolute magnitude of +18.6 (which makes it about 330,000 times fainter than the Sun), VB 10 would appear little brighter than the Full Moon if placed at the center of our solar system. It might very well have a mass below 0.085 $M_\odot$. According to a 1983 astrometric study, VB 10 may also have a planet that orbits it every five years.

In 1981, however, VB 10 lost its dubious honor as the faintest star known: astronomers I. Neill Reid and Gerard Gilmore discovered a star they christened RG 0050-2722. They place its absolute magnitude at 19 ± 1: its distance is 81 ± 20 light-years. It is a metal-rich star with space motions that place it in the young disk population of the Galaxy. Reid and Gilmore suggest it could still be contracting to the Main Sequence. A 1982 study found that RG 0050-2722 and VB 10 have virtually identical spectra, suggesting they are very similar objects.

But RG 0050-2722's brief reign as the faintest known star ended last year when Ronald Probst and James Liebert found that the star LHS 2924 had a peculiar energy distribution and a very low temperature. On this basis they identified it as a black dwarf. It so happened that LHS 2924 was already on a parallax program being conducted by David Monet and Conard Dahn. They reported a preliminary distance for the star of 28 light-years, giving it an absolute magnitude of +20.0. For now, LHS 2924 is the intrinsically faintest star known.

Two other promising systems are Ross 614 and Wolf 424. Both are red dwarf binaries, and both exhibit motions that place them among the young disk population of stars. Ross 614 B has an absolute magnitude of only +16.5. In 1977 Ronald Probst claimed its mass to be $0.07 \pm 0.02\ M_\odot$ — probably below the critical mass. Wolf 424's two components are intrinsically brighter, at absolute magnitudes +15.0 and +15.2. A 1972 study estimated the masses of Wolf 424 A and Wolf 424 B to be $0.067 \pm 0.015\ M_\odot$ and $0.064 \pm 0.015\ M_\odot$, respectively.

The ranks of such suspects may soon swell due to two space telescopes: IRAS and the Space Telescope. Launched last year, IRAS surveyed the sky at infrared wavelengths where these cool objects radiate predominantly (see "IRAS and the Infrared Universe," ASTRONOMY, March 1984). Scheduled for launch in about two years and concentrating on visible wavelengths, the Space Telescope will penetrate to apparent visual magnitudes of about +26. Based on these instruments' then-projected capabilities, astronomers R. Staller and T. de Jong predicted in 1981 that IRAS would probably fail to find any subcritical mass stars, although the Space Telescope should fare much better — they claimed it should discover an average of 90 per square degree, or almost 4 million over the entire sky.

In order to make such predictions, though, they assumed a total number of very-low-mass stars — and that question is controversial. Because of their intrinsic faintness, very-low-mass stars could abound throughout the Galaxy without being detected. Furthermore, since these stars remain visible for less than a billion years, many have vanished from view by now. If very-low-mass stars have formed at the same rate since the birth of the Milky Way, then every such star we find implies the existence of 10 to 20 others that have already cooled to invisibility. The abundance of suspect stars — VB 10, Ross 614 B, Wolf 424 A and B — within just 20 light-years of the Sun suggests that these stars are numerous.

On the other hand, they could also be quite rare. In 1982 Ronald Probst and Robert O'Connell published results of a search for very-low-mass stars in orbit about nearby white dwarfs. They chose white dwarfs because they're faint to begin with and are especially faint in the red and infrared, where very-low-mass stars shine most. (This helped lower the "noise" in detecting them.) Out of 107 white dwarfs, 15 proved double. Of these 15, only seven had red dwarf secondaries — and none of these red dwarfs had absolute magnitudes fainter than +15, despite the fact the survey would have found any as faint as absolute magnitude +20.7. The negative evidence is not conclusive, however. Perhaps something in the formation of a white dwarf disrupts a small orbiting star, or perhaps these white dwarfs are so old that any subcritical star in orbit about them has cooled too much and faded from view.

Astronomer Shiv Kumar has argued that many of the dark companions detected around nearby stars by Peter van de Kamp and others may be black dwarfs rather than planets, because many of the calculated masses lie above $0.01\ M_\odot$. (Jupiter's mass, $0.001\ M_\odot$, is probably close to the upper limit for a planet.) But van de Kamp's results have been seriously questioned by other astronomers (see "The Search for Extrasolar Planets," ASTRONOMY, December 1981) and are no longer thought to be reliable. If dark objects are ever found around other stars, orbital eccentricity may provide another method besides mass for distinguishing between black dwarfs and planets. Judging by our solar system, planets tend to have generally circular orbits. Stars in multiple systems, however, often have highly elliptical orbits. So a big

When Is a Star Not a Star?

Not very long ago, the difference between a star and a planet was simple — stars twinkle, planets don't. But while this criterion may distinguish Mars from Antares, it is far too simplistic to deal with objects like black dwarfs.

Some astronomers reserve the term "star" for any object fueled by thermonuclear hydrogen fusion — one necessarily above the critical mass of $0.085\ M_\odot$. It seems unfair, however, to deny starhood to an object that can shine for hundreds of millions of years, even if its source of light is simple gravitational contraction. Although the time during which a subcritical mass object shines is brief compared to the Sun's age, it far exceeds the total lifetime of such stars as Rigel or Betelgeuse.

Banishing subcritical objects from the ranks of stardom creates two other problems. First, it means that if a star like VB 10 is one day found to be subcritical, it has been misclassified a star up to then and should no longer even appear in star catalogs. Second, it also means that in principle you cannot automatically call a shining object beyond the solar system and within the Galaxy a star. Instead, you must first verify that the source of its energy is nuclear fusion — a difficult and daunting task.

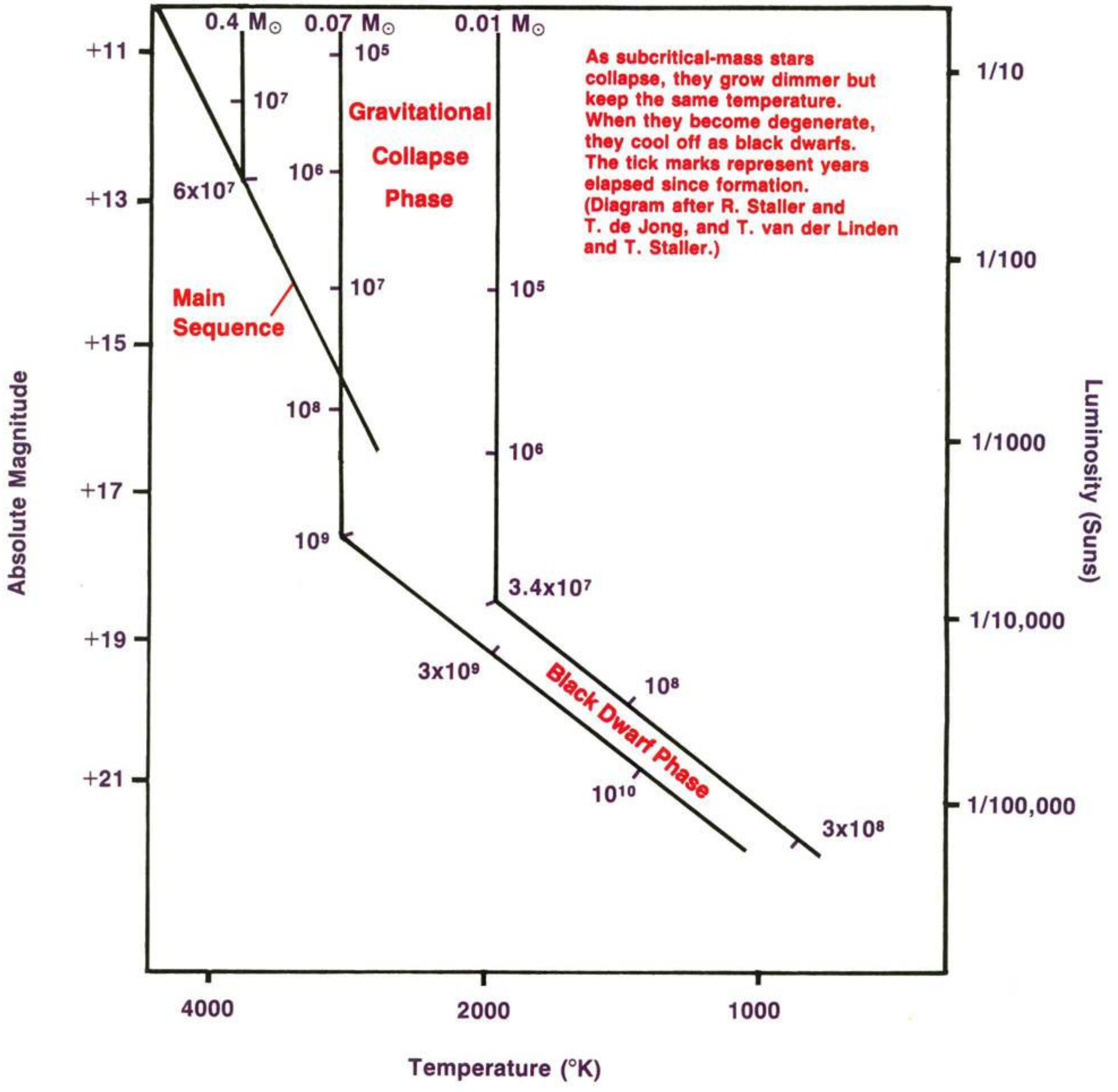
Therefore it seems much more reasonable to define a star as an object capable of forming independently of any other star. The smallest star that can form in a nebula is determined by the nebula's density and temperature. The greater the nebula's density and the lower its temperature, the smaller the star that can form. Although the minimum stellar mass is unknown, various astronomers suggest it is roughly $0.01\ M_\odot$. By our definition of a star, then, an object of Jupiter's mass — $0.001\ M_\odot$ — could never be a star, since it could not have formed in the absence of the Sun.

Well, then, how large can a planet be? Is there any definite demarcation in mass between stars and planets? Astronomer David Hughes has pointed out that the maximum planetary mass depends not on conditions in the stellar nursery, but on those in the protoplanetary disk surrounding a newborn star. Jupiter's mass of $0.001\ M_\odot$ may be about tops for a planet, and Hughes argues that objects with masses between the masses of stars and those of planets do not exist.

orbital eccentricity, along with a large mass, would argue that a dark companion is a black dwarf. Some astronomers have even speculated that our Sun has a black dwarf companion orbiting far beyond Pluto and perturbing the orbits of Uranus and Neptune. (Pluto's mass is now known to be too small to account for the observed irregularities in the motions of Uranus and especially Neptune.)

Subcritical stars also bear on the question of the initial mass function — a term that describes how many stars formed of any given mass. If the initial mass function constantly increases with decreasing mass, then very-low-mass stars are even more abundant than Main Sequence red dwarfs. If, on the other hand, the initial mass function peaks at some value and afterward decreases with decreasing mass, then very-low-mass stars may be much rarer. A related quantity is the luminosity function — the distribution of stars by absolute magnitude. The luminosity function is small for very bright absolute magnitudes (like our Sun's absolute magnitude of +5), but increases steadily and becomes quite large at the absolute magnitudes of red dwarfs: +9 to +16. The evidence indicates the luminosity function may peak around absolute magnitude +14 and then decline, which suggests that a mass corresponding to this value (roughly 0.15 $M_\odot$) is characteristic or common for stellar formation. Theoretical studies by astrophysicist Joseph Silk show that 0.2 $M_\odot$ may indeed be a characteristic size for stars produced in a nebula. But it is also possible that the luminosity function decreases past absolute magnitude +14 simply

The Lives of Subcritical-Mass Stars



As subcritical-mass stars collapse, they grow dimmer but keep the same temperature. When they become degenerate, they cool off as black dwarfs. The tick marks represent years elapsed since formation. (Diagram after R. Staller and T. de Jong, and T. van der Linden and T. Staller.)

because that's where telescopes start to miss intrinsically fainter stars — although many astronomers believe the decline sets in before any instrumental limitations are reached.

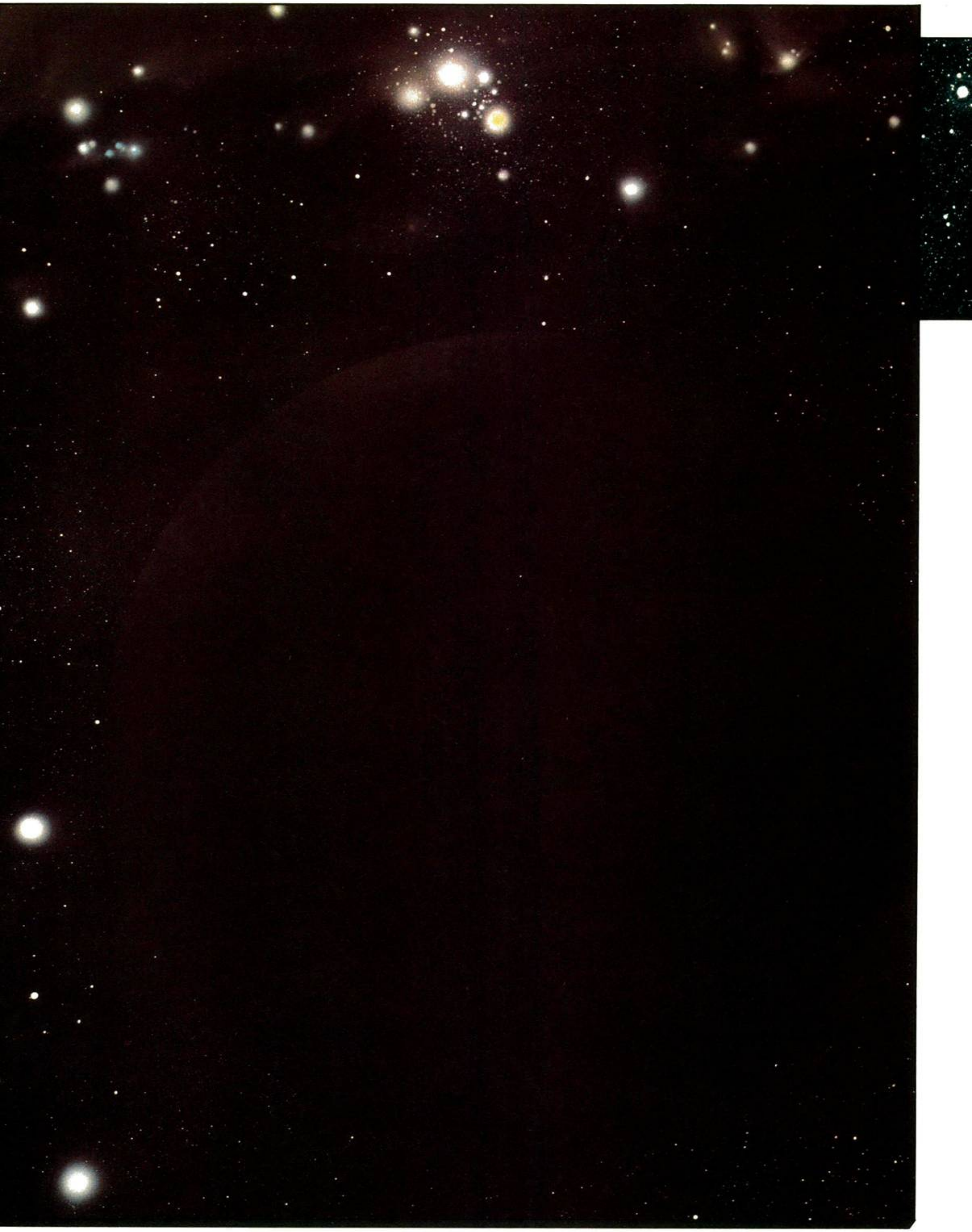
Some tantalizing evidence exists, however, that there is far more to the solar neighborhood than meets the eye. Although truly cold, dark stars cannot be seen, their collective gravitational influence can be felt by other stars. By analyzing stellar motions, astronomers can deduce the total mass density in the solar neighborhood of the Galaxy. In 1965 Dutch astronomer Jan Oort did just that and concluded that a typical spherical volume of space with a radius of 10 light-years ought to contain 18 $M_\odot$ — though this value has a considerable uncertainty. But adding up all the matter we can detect accounts for little more than half that. In the early 1970s, several astronomers believed they had resolved this "missing mass problem" when they discovered that red dwarfs were far more abundant than previously thought and that the standard luminosity function was seriously in error at faint absolute magnitudes. But a few years later, the truth emerged — these astronomers had made a systematic photometric error that caused them to overestimate red dwarf abundances. Thus the luminosity function seems vindicated at least down to absolute magnitudes +14 or +15. This was good news — but it still left the missing mass problem unresolved.

Is the mass in the solar neighborhood abnormally deficient? And if not, where is it? Oort's estimate of 18 $M_\odot$ per 10 light-year radius is very uncertain, but if it is correct — even roughly — we simply must face the fact that some mass is hiding somewhere in our vicinity. Black holes and neutron stars are possibilities, but they are so rare and exotic that they probably do not affect the overall mass balance of the solar neighborhood very much. Main Sequence red dwarfs still eluding discovery are a more likely possibility, but few astronomers like to pin all their hopes on the long shot that hordes of yet-undiscovered red dwarfs exist nearby. Black dwarfs, on the other hand, could easily make up the deficiency: If there is an average of one black dwarf per two light-year radius, then black dwarfs could account for the solar neighborhood's missing mass.

Aside from such local concerns, the number of black dwarfs in the Milky Way has profound implications for the Galaxy's evolution. Since subcritical mass stars do not burn, the matter locked within them neither changes its form nor escapes into the interstellar medium. More massive stars enrich matter with heavy elements and return it by means of novae, supernovae, and stellar winds to the Galaxy at large. The fewer subcritical stars there are, the faster the galactic material is enriched and returned. In fact, if subcritical stars are very rare, then roughly 40% of the matter in a newborn generation of stars returns to the interstellar medium after a billion years. If, however, very-low-mass stars have as much mass as all others combined, that percentage drops to 20%.

Black dwarfs could affect far more than just the chemical balance of the Galaxy — they could determine the fate of the entire universe. The universe

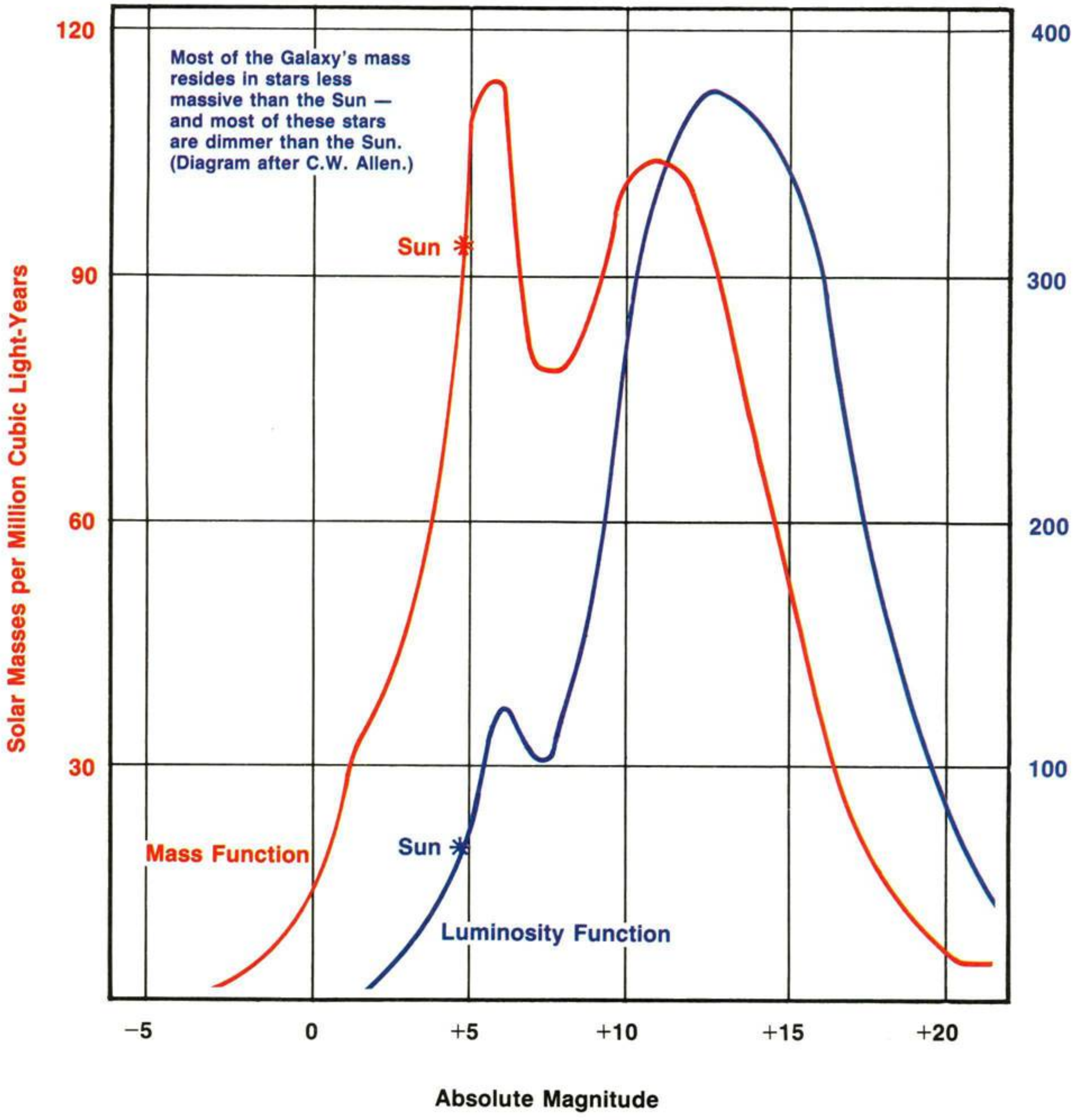
Cool and nearly invisible, black dwarf stars pose extremely difficult challenges for observational astronomers. Yet if they are as numerous as theory suggests, they have important consequences for the future of our Galaxy — and the universe itself. Painting by Mark Paternostro.



is thought to be expanding from the Big Bang. If it has enough mass, mutual gravitational attraction will reverse the expansion and cause a collapse of the universe. At present, observable matter accounts for only a few percent of the total mass to halt the expansion. Black dwarfs in our Galaxy and others could provide a good deal of the rest, along with black holes, neutron stars, intergalactic gas clouds, and Main Sequence red dwarfs. In fact, because of their low mass, black dwarfs may have preferentially escaped their parent galaxies the way low-weight atoms like hydrogen escaped Earth's atmosphere. Black dwarfs could therefore fill the seemingly empty void between the galaxies. Some astronomers have suggested, furthermore, that the Milky Way's massive corona may consist of many low- and very-low-mass stars.

These little stars, therefore, beset us with enormous mysteries. Stars too small to burn challenge our telescopes to detect them and push observational techniques to the limit. Perhaps the closest such star is only a few light-years away, attended by cold planets immersed in constant darkness and never knowing the difference between night and day. Or is the nearest dark star much closer? Does our Sun have a faithful companion that secretly attends it on its journey around the Galaxy? As always, Nature stands mute, and it is up to us to find out.

Ken Croswell is a graduate student at Harvard University. His most recent feature article was "FG Sagittae: One Piece of the Puzzle," which ran in the October 1983 issue.



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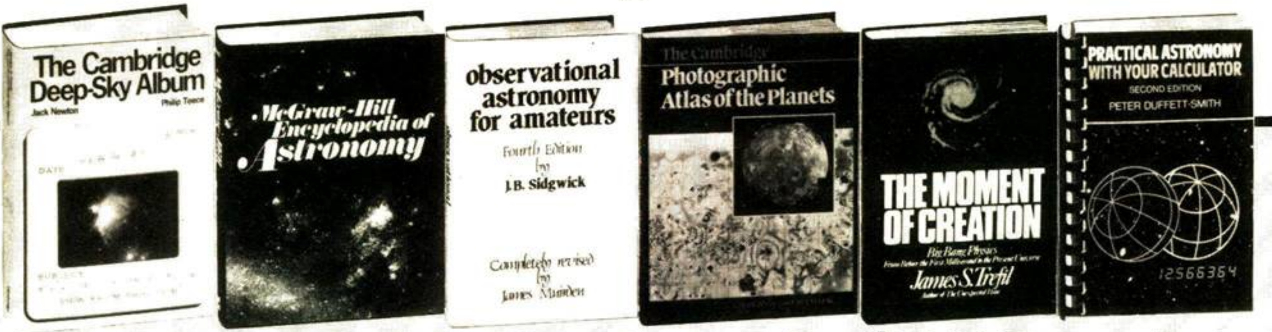

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ASTRONOMY
Forum

A Conversation with Astronaut Joseph Allen

Dr. Joseph P. Allen was selected by NASA in the summer of 1967 as a scientist-astronaut. He completed his flight training at Vance Air Force Base in Oklahoma and subsequently served in a variety of capacities at NASA, both in Washington, D.C. and in Houston, Texas.

In March 1982, Allen was chosen for his first flight into space — mission specialist on STS-5. STS-5, the first operational flight of the Space Transportation System, was launched from Kennedy Space Center, Florida, at 7:19 a.m. EST on November 11, 1982. Allen was accompanied into orbit by Vance Brand, mission commander, Robert Overmyer, pilot, and William Lenoir, mission specialist.

Five days, two hours, 14 minutes, and 25 seconds later, *Columbia* and its first four-man crew touched down at Edwards Air Force Base, California, after successfully deploying two commercial communications satellites. The satellites were the first to be deployed from the Shuttle's payload bay.

Allen is now on active flight status in the Astronaut Office at Johnson Space Center in Houston. In March of this year, he shared with us his experiences aboard *Columbia* and his thoughts about the future.

ASTRO: It's launch day, you're strapped into your seat, and you're ready to go. Describe what you heard, felt, and saw during liftoff.

Allen: Okay. First of all, let me say for the record that I was the first person to ride as a passenger on an American launch. Previously, astronauts have always had assigned duties to do should the necessity arise. This, of course, included my crewmates. They were on the flight deck and could have had a busy few minutes if the launch hadn't gone exactly the way we wanted. They were very intent on watching the instruments and displays that told them how the launch was proceeding.

In contrast, I was on the mid-deck. I had no controls or displays I was responsible for, or switches to throw. So I could reflect on what was happening and literally rode as a passenger.

I was strapped into a seat, a rather normal-looking chair back against the airlock, looking straight ahead into the lockers where we store the equipment for the days in orbit. Of course, at launch *Columbia* is tipped up vertically so you're lying on your back, looking up at the ceiling and the ceiling happens to be the lockers, which are looking back down at you. I thought, "I hope those lockers are tightly fastened in!" They're like dresser drawers — they pull straight out and they have little thumbscrews that lock them in place. I had this mental image of one of those thumbscrews very slowly backing out during the eight minutes the engines were running — the kind of thing you see in a Road Runner cartoon. Then finally, one of the drawers comes loose in the mid-deck and dumps out!

The launch loads are three g's, and so three times the force of gravity is tugging at those drawers, trying to open them. Things like that passed through my mind. It did not make me anxious. I was rather amused by the thought and, in fact, joked with those upstairs in the vehicle about it.

To ride inside the Shuttle is very much like one would imagine in viewing it from the outside. It is loud — very loud! We launched without pressure suits on, but we still wore simple helmets that have a lot of ear protection. Even so, you're aware of an enormous amount of noise around you. Some of it you hear through the helmet, and a lot of it you just sense in your bones and your body. It is a very heavy, sharp vibration. The acceleration is readily apparent. There is a lot of shaking and banging around.

This goes on for two minutes while the solids are burning. Then there is a very dramatic decrease in the acceleration. You feel as though you are coming forward in the shoulder straps. You're not really; it's just that you have gone from about three g's acceleration back to one g.

ASTRO: That's because the solid rocket boosters, the SRBs, have burned out?

Allen: Yes. When you feel the force unload, you know the SRBs have burned out. Then there is a loud bang, a loud whoosh, and a flash of light. That flash occurs when the two SRBs are jettisoned.

ASTRO: What exactly could you see from the mid-deck?

Allen: On the mid-deck, there's a small porthole about six inches in diameter on the left side of the

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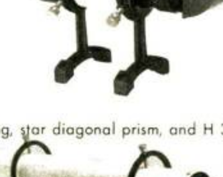

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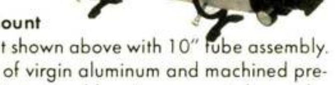

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vehicle. The cover to that port was open. I could see the tower go past, and I could tell from the changing color of the sky that we had rolled 90°, tail to the east. Very quickly, within the two minutes that the solids were burning, the sky went from bright blue to a deep blue to a much deeper blue to black — the blackest black I'd ever seen.

ASTRO: That color change from blue to black meant that you had gone into space.

Allen: Yes. In those two minutes we had gone above the atmosphere.

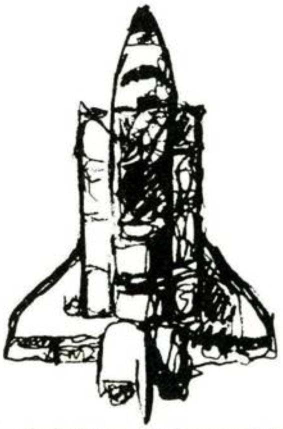
Getting back to the launch, after the SRBs are jettisoned, you feel the g forces come back on — the three g's. This is because the main engines crank back up to continue the burn. Now what had been a loud, rough, and mind-jolting ride for the first two minutes becomes just as smooth as glass. You can feel the main engines push you ahead; you can barely hear them. They make more of a humming sound than a roar. I had the feeling that we were being propelled into space by a large electric motor. It was almost like riding on a subway. And that continued for the next six minutes — a total of over eight minutes burn time on the main engines.

Then you feel yourself unload again against the straps. Now you're noticeably lighter. You're still strapped in and you feel as though you may be back down to one g. But if you're in orbit you should be down to zero g. I had a pencil in my hand and let go of it, kind of carefully to keep it from falling. And it didn't fall at all! It floated right in front of my nose. I knew we were in a good orbit because I heard the crew on the flight deck talking. I knew that the numbers were coming out just right. I did not feel like I was in zero g because I was still tightly strapped to the seat. But when I unstrapped, I floated out of my seat. And that's a most unusual feeling!

ASTRO: How would you describe the sensation of weightlessness?

Allen: That's a tough one. In a swimming pool, you tend to sink; you're not really floating on the top. When you're weightless, you just feel buoyant and you feel that way all over. If you really relax, your arms tend to float out from your body. Your hands float. Just everything floats! You float around the spacecraft. It's perhaps a little like being a scuba diver; you can go head first from place to place, using your hands and arms to move along and also to stop you once you get somewhere. The only difference is that making a swimming motion doesn't do you any good — you don't move.

Oh, it is really fun . . . really fun! You let things go and you don't have to put them away. They just float there in front of you. But you better pick them up or grab them again quickly — by quickly, I mean in 10 or 15 seconds — because although they don't fall, they will meander away. It's partly the circulation of the air in the Shuttle that moves objects in different ways. And it results in things *forever* getting lost. I mean cameras, books, articles of clothing, packages of food — anything that's not fastened for a few seconds will wander. And then *you* have to look around to find where it wandered off to.



Zero gravity makes the handling of liquids almost like slapstick. That amused me immensely and still makes me laugh when I think about it. At first, we were all considerably more awkward than we like to admit because of the zero g. You're floating around with as much skill as a baby deer trying to walk on ice — as awkward as can be in the beginning. You're losing things out of your pockets, or a checklist will float by and you'll lose it because you forgot to hook it down. While it's happening, you tend to be frustrated and angry. But when you look back on it, it's really very amusing.

ASTRO: What are your preparations for reentry? And would you describe the reentry from the deorbit burn to wheel stop?

Allen: Okay. The preparations went as we had planned. It takes a couple of hours. Picture yourself on a camping trip. When it's time to leave, you go about taking down the camp. That's basically what we were doing. We were putting a lot of things away in containers to bring them home and, in general, tidying up around *Columbia*.

The deorbit burn went as scheduled using the OMS engines. As always, they burned right on time for exactly the right amount of time. They're very smooth running, very quiet engines. You almost feel as though an electric motor has been turned on, as opposed to an actual rocket engine. The burn ended while we were in broad daylight. In fact, the Sun was squarely in our eyes as it came through the front windows of *Columbia*. Very shortly after the burn, the Sun set again as, of course, it does every 90 minutes in orbit.

From then on we were in darkness and we entered in the nighttime as we came across the Pacific Ocean. After the burn and after we went into darkness, the vehicle was oriented in the proper way — the nose-high, nose-forward attitude. Then, we settled into the atmosphere and little by little the g forces started to build. They went from zero gravity and climbed to 1.7 g's. As this happened, you could begin to hear a sound outside — a whisper that relentlessly increased to a loud roar. That, of course, was the onset of wind noise. The other thing that happened was truly quite spectacular. You could begin to see a glow coming from outside the vehicle. You could see that glow creep across the windows. It went from a light red-rose color to a bright and intense orange color, and then it became whitish. It was very bright indeed. Not as bright as the Sun, mind you, but very bright. That glow — the fiery heat of reentry — walking across the windows was very dramatic! We knew from it that we were not practicing a drill or a simulation, but that we were making a real reentry.

Then, at Mach 10 as we approached the California coast, the Sun rose again and the glow was gone. We came out of blackout and once again could communicate with Mission Control. Mission Control informed us that we were right on the proper energy state and ground track. That was good news to us, although the navigational equipment onboard had told us that as well.

The remainder of the entry went exactly the way we'd practiced it hundreds and hundreds of times. Vance Brand flew *Columbia* according to the profile and the procedure that we had learned, in an absolutely flawless way, to a point above the landing field — a fictitious circle in the sky — that we call the heading alignment circle, or HAC. Once on the HAC, you just bank the wings over in about a 30° bank, and then *Columbia* turns around the circle. Then, you roll the wings level as you make your final approach, keeping them aligned with the runway. And Vance did that just according to plan. The only difference was that there were clouds below us, so we could not see the desert or the runway or anything like that.

Then we dropped through the clouds and there was the runway — right there, right in front of us! Bob

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Overmyer called out that he could see the runway, and Vance looked up at it. Bob called out air speeds and altitudes as we got down close to the runway, and we landed so smoothly I couldn't feel the wheels touch. It was a perfect landing right where we wanted to be. So there we were, back home again after two million miles!

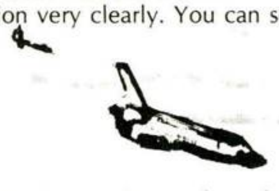
ASTRO: Did you have any free time in orbit? If so, how did you pass the time?

Allen: With a crew of four, in contrast to two in the past, each of us had more free time than any crew before us. What I did was to look out the windows, mainly, and take pictures. In fact, I had a hard time taking my eyes from the windows. It was just a beautiful view! There are many windows in *Columbia* — large windows — and it's like being in a gondola. You could look out in all directions and see incredible things all around you.

ASTRO: We've all seen pictures of the Earth from space, and the view is stunning. How do the pictures compare to the real thing?

Allen: They compare like pictures of the Grand Canyon compare to seeing the Grand Canyon. Your eyes have a sensitivity and a keenness that film doesn't begin to share. Part of it is psychological though, because you know you're actually there.

But there is a very real difference — when you look out, you see things in three dimensions. You would think that from orbit the globe would look rather flat, as though you were in a high-flying airplane. But in fact, that is not the case. You see a third dimension very clearly. You can see the mountains coming up from the surface of the Earth. You can see the clouds well above the surface of the Earth. You can see the shadow of the clouds on the Earth. That shadow, that relief of clouds and mountains and Earth below is very striking and gives you a sharp feeling of three dimensions. That third dimension is really an overwhelming aspect of the view from orbit.



In addition, there is a dramatic feeling of speed. From the spacecraft, you feel as though you're going rapidly across the surface of the Earth. Your altitude of some 200 miles does not diminish the sense of the five-miles-per-second speed across the oceans and continents below.

ASTRO: How has the mission changed you?

Allen: Well, I don't think it did dramatically nor did I expect it to. However, I have always believed that any journeying out from your home tends to change you a little bit. Maybe the longer the trip, the more it changes you, and this is no exception. I think if a trip doesn't change you, you haven't been paying much attention. I suspect you use the same words to describe trips you've gone on. This was in no respect any different from that. It was farther; it was a lot faster. But I don't think the changes due to a space flight are any more dramatic than they would be with any other journey a person would take.

I'll tell you a rather amusing story. When you're in space, the lack of gravity unloads your backbone a little bit so that you actually get a little bit taller — about an inch to an inch and a half taller. I'm not that tall a person anyway, so I thought, "Wouldn't that be terrific!" Once in orbit, before we put our spacesuits on, we measured ourselves and sure enough, I was about an inch and a quarter taller! But the sad part was . . .

ASTRO: It didn't last.

Allen: Within six hours of when you're back on the ground, standing up in one gravity, you're right back where you started.

ASTRO: One of the primary criticisms of the Shuttle program is that money is being spent on the Shuttle at the expense of planetary exploration.

Allen: That is an issue that really should be discussed, and ultimately, a good balance ought to be achieved. I say that, underscoring a prejudice in me that I want you to recognize. There's nobody more interested in scientific research than I am, be it planetary exploration, bigger and better telescopes, or sky surveys of all kinds. Such investigations excite me every bit as much as a Shuttle flight. It would be catastrophic if this country would get out of the business of doing research in these areas.

Having said that, though, I think it is also very difficult to say with certainty that, because the Shuttle is getting some money, the planetary program is not, as though it's going from one place to the other. I think that is absolutely incorrect. That same argument was put forth in the Apollo days. Statements were made that because the Apollo program was getting so much money, science in space was not. But even as that argument raged on, science in space was getting about $500 million a year. That was big money! In fact, that was as much money as the National Science Foundation was getting for all other science. Yet there still was that argument that space science was not doing very well *because* of Apollo. In my view, science did very well in those years, maybe even because of Apollo.

The question is: How much money would be going to space science if there were no space program that involved either the Shuttle or expendable launch vehicles of the old days, like an occasional Apollo spacecraft. I rather think if the country weren't doing those things, it would be backing out of space altogether, including all planetary exploration and astronomy.

ASTRO: Do you envision the day when the average reader of ASTRONOMY will be able to buy a seat on the Shuttle?

Allen: Well, I envision the day when passengers will be able to come aboard. I think it will be very expensive the first times, exactly the way a trip around the world was very expensive years ago. In fact, that's still very expensive. Perhaps only the wealthiest people will be able to afford to ride the Shuttle in the beginning.

I will point out that there is a great view of the heavens from down here. It is not dramatically improved in terms of naked-eye viewing to get that 100 or 200 miles closer. What is most awesome about the view from orbit is looking back at the Earth. Astronomers tend to be more sensitive and more reflective about what is within the universe they're looking at, and I dare say they would be very much moved by the view of the Earth.

ASTRO: As you look down the road, what do you see as the future of the Shuttle in particular and the space program in general?

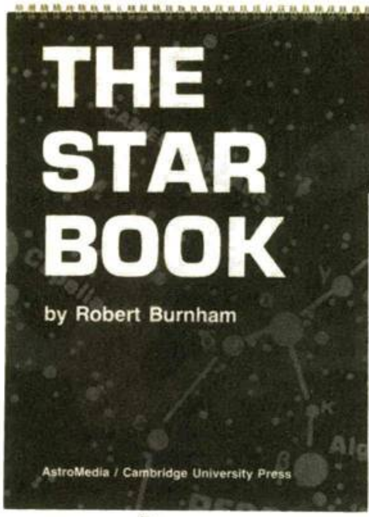
Allen: I think the future of the Shuttle looks very bright. As proven by our flight and the others that have followed, it can be used to transport things up and back. No question about it, it's going to work in that regard. That was its design philosophy and that philosophy has shown itself to be viable. I think we'll use each of the orbiters several hundred times.

Now, what else will follow? The crystal ball gets a little hazy. But we basically have the railroad going up into space and now we need a depot in space to make the system symmetrical.

ASTRO: A Space Operations Center?

Allen: We've got the train and now we need a depot, a place in space to aggregate equipment, supplies, perhaps propellant, quite possibly living quarters — even temporary quarters — and it might even be called a Space Operations Center. But that's just a fancy word for something I'll call a depot. That must be the next step. The *only argument is when* to do it, and that brings us into the political arena.

Michael A. Sposito
Curwensville, PA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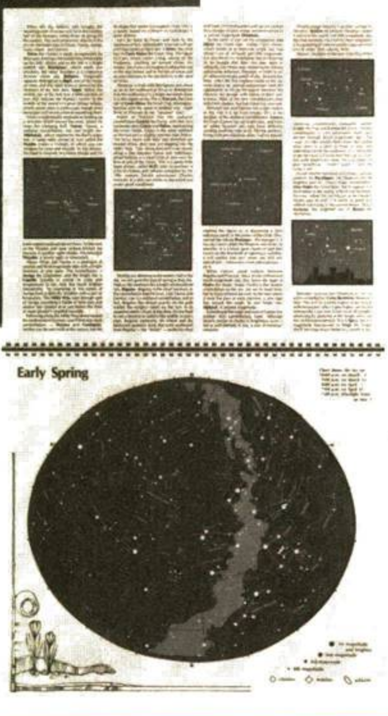
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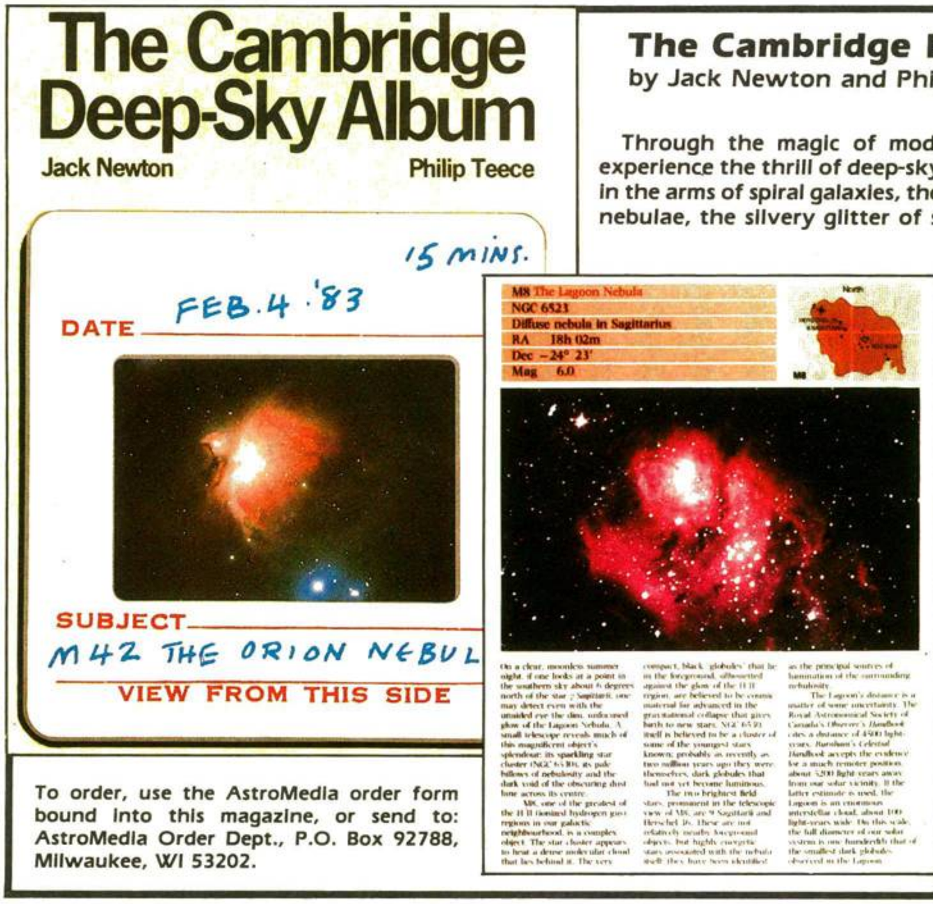
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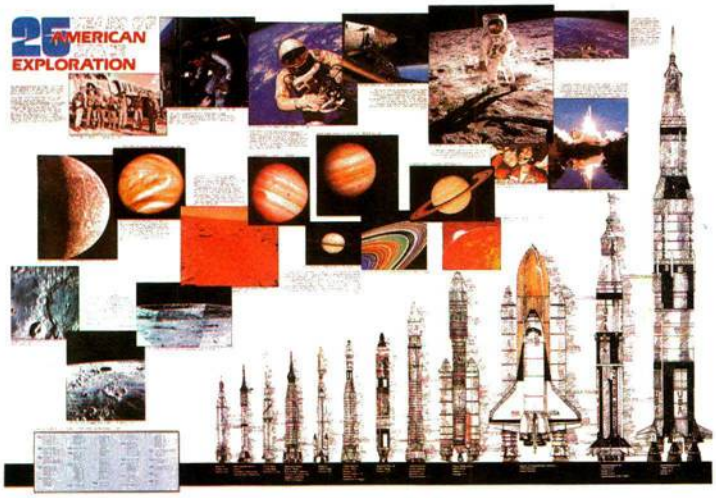

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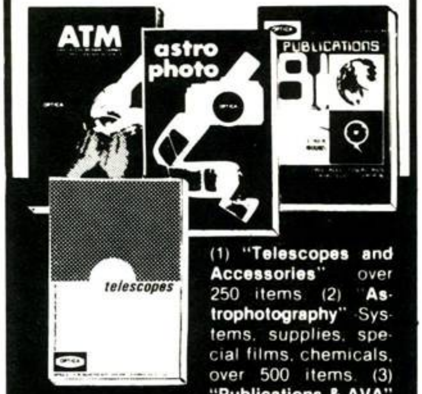

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To encourage safe observation of the sun, Celestron offers a free report on solar viewing and photography. Send a self-addressed stamped envelope to:

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ASTRONOMY
In Focus

Voyager to Pluto?

Sir / I was re-reading in the April 1983 issue about Voyager headed for Uranus and Neptune, and thought, "How about Pluto, too?"

The diagram of Voyager's trajectory on page 8 of that issue led me to wonder why we can't use Neptune's gravity to sling Voyager off to Pluto instead of sending it out of the solar system.

Marc Conza
Lehigh Acres, FL

Mr. Conza / NASA's original plan for the Grand Tour did include a visit to Pluto, but that was assuming a launch several years earlier than what Voyager actually achieved. Given the positions of the outer planets at launch, and given the trajectory refinements made during the mission, it simply isn't possible anymore to send Voyager 2 past Pluto after its Neptune encounter. The problem is that the "right turn" the craft must make there is so sharp that Voyager would have to swing closer to the center of Neptune than the planet's surface.

More on Starflight

Sir / Those of your readers who read the account of our Daedalus project in your October 1983 issue might like to know that the theme has since been developed and expanded in a number of "red cover" issues of the *Journal of the British Interplanetary Society*, which are concerned solely with interstellar exploration.

The subject matter of these issues goes beyond the Daedalus project and deals with a whole range of problems of interstellar exploration, including not only technology but space biology, communication, terraforming, etc. The range is most exciting.

The issue on antimatter propulsion was particularly outstanding. Unfortunately, our supply was exhausted within a few weeks, though we plan to reintroduce this as a booklet for general readers shortly.

Meanwhile, I have available a number of other "red cover" issues and will gladly send specimens free of charge to any of your readers who care to ask for them, for as long as our stocks last.

L.J. Carter
Executive Secretary, B.I.S.
27/29 South Lambeth Road
London SW8 1SZ
England

Pulsar Discoverer

Sir / Many thanks to George Reed for the Forum article on the discovery of pulsars in the December 1983 issue of ASTRONOMY. As a woman, I am interested in achievements throughout history that were credited to a man but actually accomplished by a woman.

As a worker in computer science and a student of life, I would like to see my achievements bear my name if I were in Bell's place. Certainly there is part of me that wants to give a great work to humanity and science — no matter whose name gets the credit. Yet there is another part that wants to see justice done. I am grateful to the astronomical community members who have acknowledged Susan Jocelyn Bell as the discoverer of the first pulsar. Cheers!

Donna Chato
Livermore, CA

Astronomical Networks, Anyone?

Sir / I just read in the December 1983 issue an article entitled "A Symposium on Telescope Control with Microcomputers." Another use for micros, one in which they do an excellent job, is transferring information from one person to another. It seems to me that it might be time to establish an astronomy users group.

Some topics that could be covered:

1. lists of astronomy clubs
2. coming events
3. personal and club announcements
4. for sale and wanted ads
5. exchange of ideas for use of computers and other equipment
6. exchange of programs for use in astronomy
7. exchange of observing data.

Anyone interested?

Russell Chabot
West Allis, WI

Aleph is No Bull!

Sir / In the January issue of ASTRONOMY, you said that the first letter of the Hebrew alphabet, aleph, also meant bull or ox. I must correct you. Three possible words for a bull may be "shor," meaning ox, "par," meaning a bovine, and "bakar," meaning cattle, in a more general sense. Granted, in the Hebrew and ancient Babylonian calendars the year begins with the first New Moon of the spring equinox, which corresponds to the time of Taurus the Bull, but your vocabulary was slightly off.

Kenneth L. Graber
New Rochelle, NY

Ecological Disaster

Sir / I was reading merrily along through "Possible Planets" in your February 1984 issue when I ran savagely aground on this phrase on page 69: ". . . the recently discovered *ecologies* that thrive at regions where the sea floor spreads" (my emphasis).

Mr. Gillett may know a lot about geology. He may even have his organic chemistry right, for all I know, since critters — not chemistry — have always been my forte. But he slid from planets to critters and butchered critterdom in the process, and when I read the above phrase I began to wonder how much of his article was written out of his depth.

Ecosystems thrive. Ecology is the study of those ecosystems. The use of "ecology" for "ecosystems" is an abomination that has been fed by media ignorance for some years.

T.J.J. Opilla
Laurel, MD

Meteorites or Hailstones?

Sir / I just finished reading the very interesting article by Jeffrey K. Wagner on "The Source of Meteorites" (ASTRONOMY, February 1984) and thoroughly enjoyed it — as I do most of the material each month. A minor error should be noted, however.

Mr. Wagner states that the fall of "stones from heaven" is mentioned in the *Bible* (Joshua 10:11) and implies that this is an early reference to meteorites. Looking at the original Hebrew text, I note that the word translated "stones from heaven" in the King James Version is actually the Hebrew word *ebenbarad*, a compound word meaning literally "stones of hail." Except for the verse in Joshua mentioned above, the word *ebenbarad* occurs in only one other place in the Bible — Isaiah 30:30 — where it is correctly translated in the King James Version as "hailstones."

This minor linguistic error did not, of course, detract in the least from the excellent quality of Mr. Wagner's article. Keep up the good work, and thank you for a terrific magazine.

Dr. Wm. F. Duerfeldt
Ohio University
Athens, OH

Sighting the Shuttle

Sir / I am a Danish amateur astronomer living ten miles south of the Danish capital, Copenhagen. On November 28, the Space Shuttle *Columbia* was launched with the European Spacelab payload in its cargo bay. Because of the highly inclined orbit, I knew that *Columbia* would pass over Denmark several minutes after the launch. I went out in the backyard and looked: Columbia arrived as a very bright and clear "star" of magnitude −3.

It was flying from west to southeast. As *Columbia* passed near the star Altair in Aquila, something fantastic happened. About five degrees behind the Shuttle and a little bit below it, I saw a bright orange "star" shining at magnitude −4. It had about the same color as the famous star Betelgeuse, and roughly the same speed and direction as the Shuttle. After 10 or 15 seconds, the sight was over as the orange star faded out. *Columbia* disappeared into the horizon haze a few seconds later.

I think what I saw was the external tank burning in the atmosphere. Denmark is north of East Germany, where NASA stated that it would burn up on re-entry. Some other people here in Denmark also saw the same phenomenon. It is fantastic to see such things live!

Lars Spatzek
Dragor, Denmark

— We saw the Shuttle here in Milwaukee, too, as a bright star. Incidentally, a quick calculation suggests that if you could catch up and "lock on" with a telescope, it would be possible to see the Shuttle as a 10-arcsecond-long image!

Ooops!

The photos on pages 9 and 16 of the February 1984 issue were taken by Scott Patterson, and the photo of NGC-2371/2 on page 78 was taken by Martin Germano.

Static charge in the early solar nebula may have led to lightning *bolts*, not lightning balls as stated on page 20.

We apologize for a production problem visible in the Backyard Astronomer. As a result, the map of Gemini fails to show the Milky Way outline and does not have the correct background tone.

Behind the Scenes | Searching for Planets

Dana Patchick

Some people collect seashells, others collect stamps. For a few years, I was a planet collector. When I read, as a teenager, that Copernicus never saw the planet Mercury in his whole life, I decided to do him one better and see *all* the planets. Jupiter, Saturn, Mars, and Venus were easy — I found them within a week of deciding to do it.

Mercury, true to its reputation, was considerably more difficult, but I spotted it the first time I tried. It hung as a flicker of light in the trees over the local high school athletic field. I confirmed the find with my dad's 7 x 35 binoculars, but with the confidence of a 13-year old, did not understand why Copernicus hadn't seen it. *I* could see it just fine.*

In the year after I completed my first telescope, a 6-inch reflector, I found Uranus and Neptune. Both planets are easily identifiable because their images are nonstellar even at fairly low magnification. I searched for Pluto, too, but it eluded me.

I found some asteroids, which, although they are not really planets, are nonetheless necessary when attempting to "do" the solar system. I looked for Pluto again when I finished my 8-inch f/10 planetary Newtonian, but it was still too faint.

There the matter rested. Another year passed, and I completed a 12-inch reflector with a big wooden yoke mounting. Within weeks of installing that telescope in my "chicken coop" back yard observatory, I had Pluto.

Pluto is now brighter than it was 20 years ago, so a 10-inch scope, and probably an 8-inch under dark skies, will suffice to locate this tiny speck of light. But as much as the telescope, careful technique counts — and once you've found what you *hope* and *think* must be Pluto, until you confirm your find by observing its motion, you can't claim to have observed Pluto. Though I might have *seen* Pluto the first night I looked, I had not *observed* it until the second and third nights, when I confirmed its motion against the stars.

In preparing the finding charts for this month's Gazer's Gazette, Dave Eicher (who wrote the article) and I took pains that ASTRONOMY's charts are not only accurate (although a computer actually plotted all three maps, we checked its work at every step), but detailed enough to insure that you will be able to locate a difficult planet with them. I plan to be out there looking for Pluto this year, and hope you will be, too.

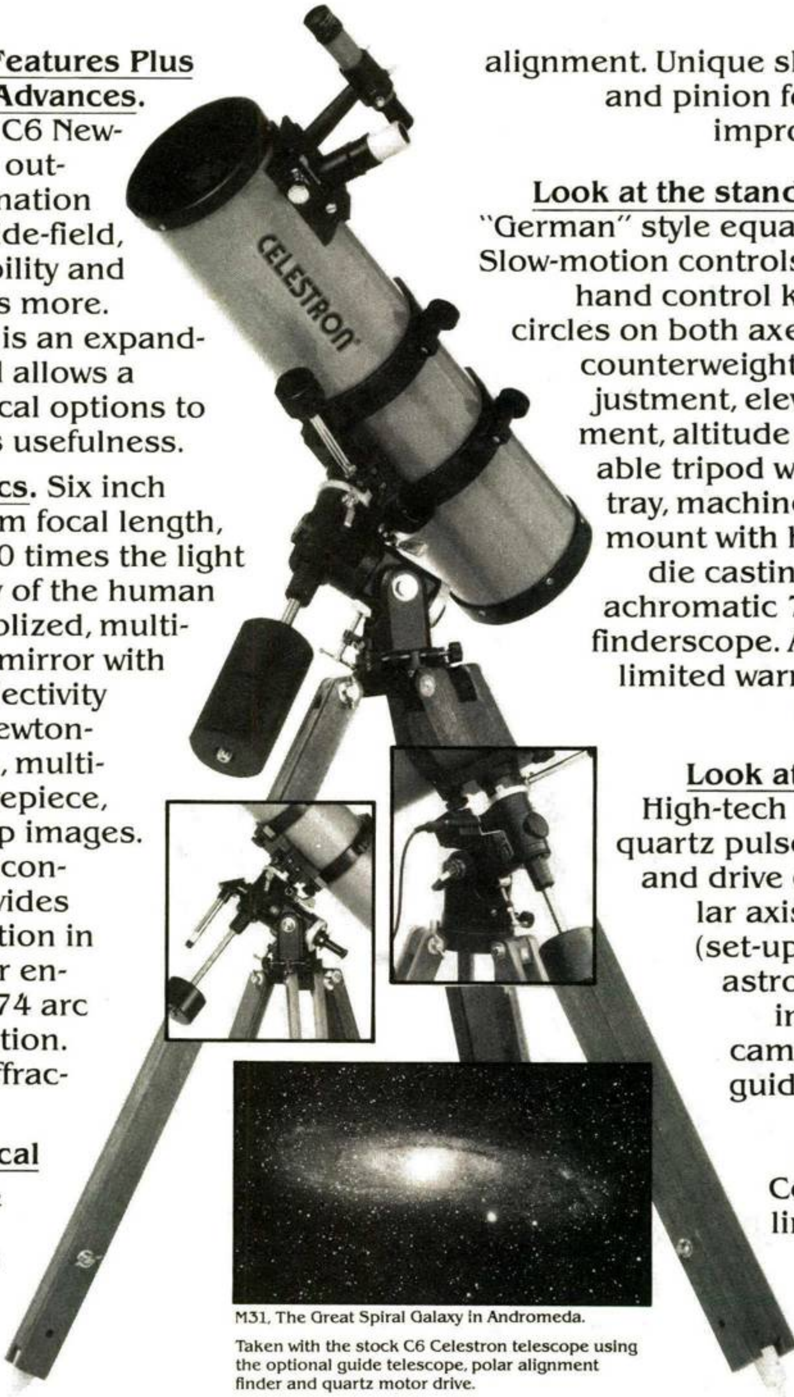
Sincerely

Richard Berry

Richard Berry
Editor-in-Chief

**In fact, Copernicus probably did see Mercury, but he complains that its position is difficult to measure.*

CELESTRON'S HIGH-TECH NEWTONIAN.



M31, The Great Spiral Galaxy in Andromeda.

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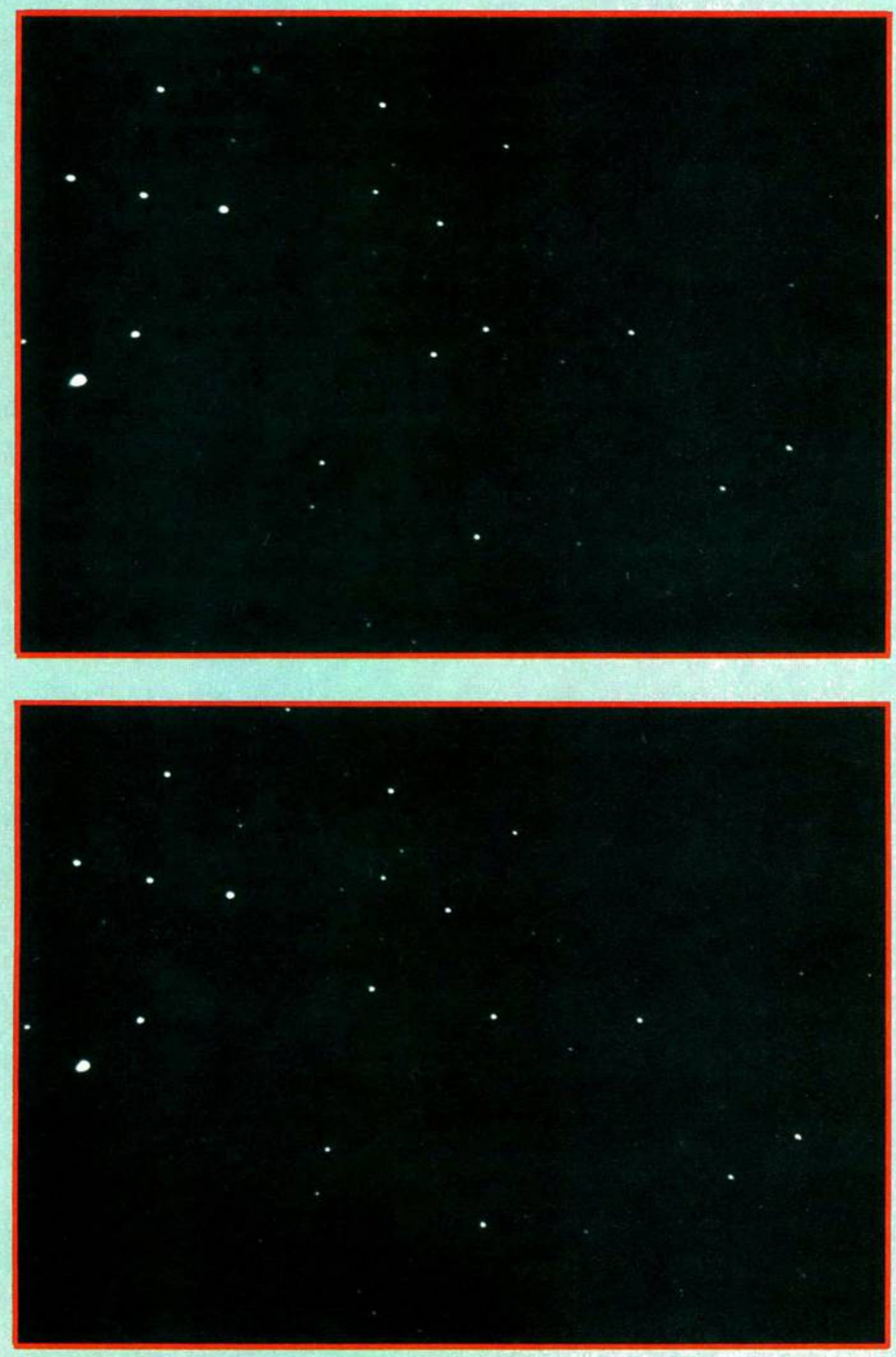
Gazer's Gazette

How to Hunt Down Pluto

The thrill of detecting the remotest object in the solar system is an old part of observational astronomy, one that poses a special observing challenge. Pluto is visible in telescopes 8 inches or more in aperture, and can be photographed easily with a 400mm telephoto lens and a few minutes' exposure. (Under excellent seeing and transparency, Pluto may be visible in a 6-inch telescope and photographable with a 200mm lens.) Pluto comes to opposition — lying in the opposite direction from us as the Sun — at 16h UT on Friday, April 20, when it will shine at magnitude 13.7. Full Moon occurs on the 15th, but you can observe the tiny starlike planet with relative ease several days before or after mid-month, and afterward for many weeks before it slips into conjunction with the Sun late in the year.

How do you go about finding such a tiny, dim object floating about a sea of faint stars? Luckily, Pluto is currently in the constellation Virgo, away from the richer starfields that occupy some parts of the ecliptic. But locating it will not be a simple operation — Pluto moves across the sky very slowly, and even in Virgo it is lost among many faint stars. If you have an 8-inch or larger scope, wait for a crystal clear night to try to find Pluto. Locate Spica and move northeast to the 4.3 magnitude star Tau (τ) Virginis as shown in chart A. This is your starting point; center your finder telescope on this star.

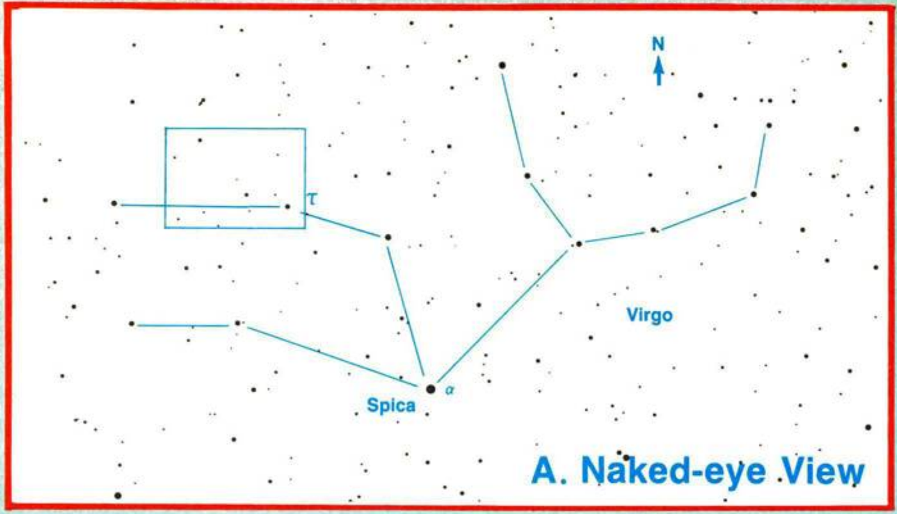
Now switch to chart B, a finder-telescope's-eye view of the Pluto field. Note that south is now up, and that τ Vir is at the upper left portion of the area. The bright stars CU Virginis (magnitude 4.9)



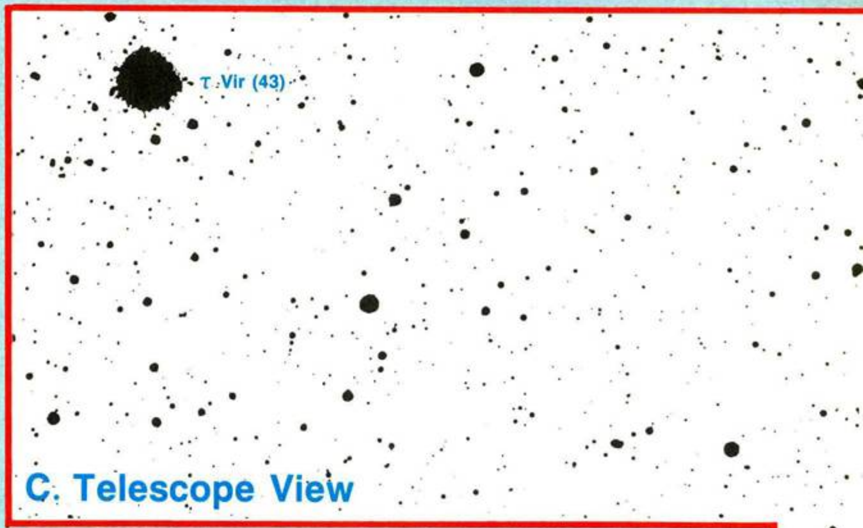
Which speck of light is Pluto? You'll ask yourself this question repeatedly when you go out attempting to hunt down the tiny planet. Only careful sketching and comparing will reveal that Pluto — here roughly centered in each frame — has moved. These photos, made two days apart, are by Paul Roques.

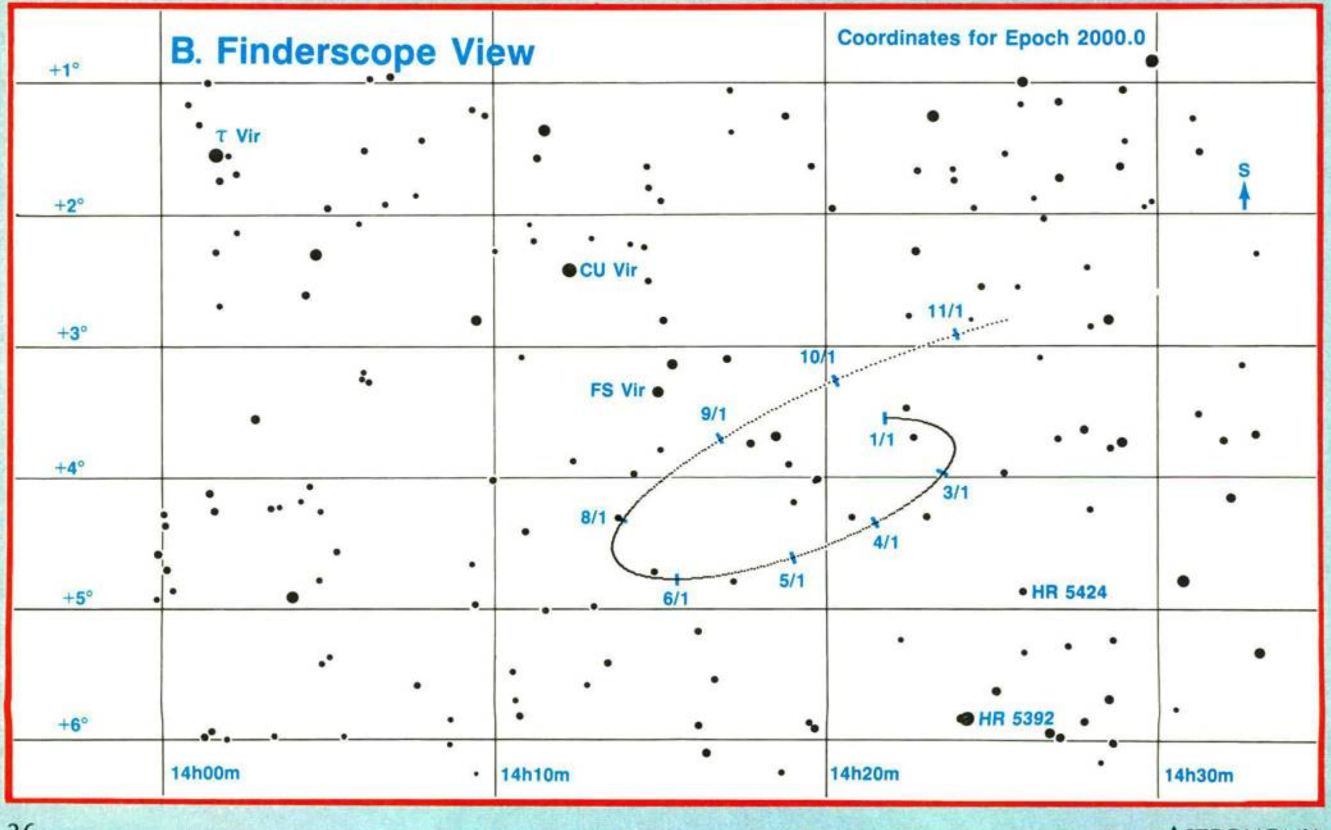
and FS Virginis (magnitude 6.6) serve as guideposts for star-hopping. Use them to move your finder down to the X-shaped group of stars near the center of Pluto's loop. If you're using setting circles, offset the coordinates on your telescope by about 17′ west in R.A. and a little over 2° south in Dec. This gets you to the familiar X pattern and close to Pluto.

On chart C, the telescopic finder for Pluto, the X shows up much as it does on the finder star map. (Chart C uses a background star map photographed in blue light, causing blue stars to look more prominent than they will appear and de-emphasizing red stars.) Now that you're in the right area, count to the correct day to find where Pluto should be. Tick marks


N
τ
Virgo
Spica
α
A. Naked-eye View

To find Pluto's position for sketching or astrophotography, first use chart A to locate the correct section of Virgo where the fourth-magnitude star Tau (τ) resides. The orientation for this map is north up, east to the left, just as the real sky appears. Next, move your finder telescope to Tau and check the field to verify it with chart B, which has south at top and east at right. Finally, use chart C to move into Pluto's exact position, star-hopping down through the bright stars CU and FS Vir; stellar magnitudes with decimals omitted are given in parentheses. As you approach an X-shaped pattern of moderately bright stars, you need only check the date in UT to pinpoint the tiny speck of light representing the icy world Pluto. Tick marks show the 1st, 10th, 20th, and 30th of each month.


τ Vir (43)
C. Telescope View

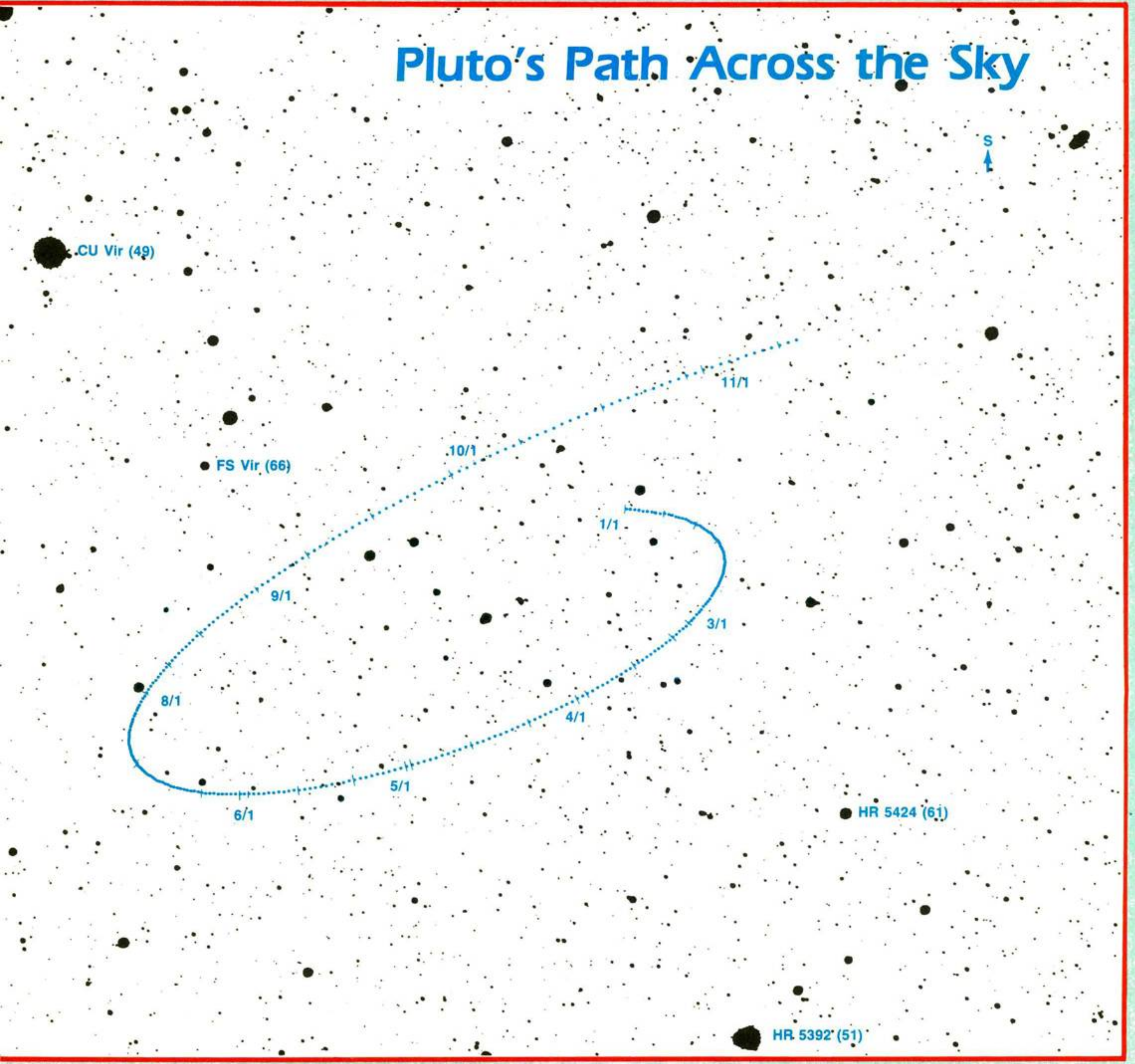

B. Finderscope View
Coordinates for Epoch 2000.0
+1°
+2°
+3°
+4°
+5°
+6°
τ Vir
CU Vir
FS Vir
S
11/1
10/1
9/1
1/1
3/1
8/1
4/1
5/1
6/1
HR 5424
HR 5392
14h00m
14h10m
14h20m
14h30m

on the map are for 0h UT on the date shown, which means that you should look at the *next* day's dot, i.e., 7 p.m. CDT on the 14th is 0h Universal Time for the 15th.

Once you've pinpointed the exact location of Pluto, switch to a medium magnification of 15x to 25x per inch of telescopic aperture and zero in on Pluto's supposed location. You will see a lot of faint stars — one of which is Pluto. Use the chart to locate the correct place, next to some recognizable pattern of stars on chart C. But the planet is not moving fast enough to change its position right in front of your eyes. Make a detailed sketch of the stars in the immediate area of Pluto's location and repeat the entire process a night or two later. After obtaining two sketches of the same field, you can duplicate the achievement made by Clyde Tombaugh — Pluto's discoverer — by looking for the faint "star" that moves in the interim and is actually Pluto.

If you have a telephoto lens or 4- or 6-inch telescope, you may want to attempt photographing the elusive planet. After you've set up your telescope, polar-aligned it, readied your camera, and checked the telescope's guiding, you can find a suitable guidestar. The most logical candidate is Tau, but if a fourth-magnitude star is too glaring over the course of a few minutes' exposure, you can pick a fainter star in the immediate area. Take a normal 15- or 20-minute exposure on fine grain film like Technical Pan 2415. After making two exposures of the same field on two different nights, compare the two with a magnifier or a blink comparator and you'll see that Pluto has moved with respect to the countless background stars.

Having successfully located Pluto, you belong to a very select group of backyard astronomers. Few observers own large enough equipment, and fewer still know the exact position of the planet, let alone actually go out and find it. Is Pluto visible in a 6-inch telescope? Can it be photographed with a 200mm lens? How easy is it to identify for the average amateur? Let ASTRONOMY see your results, planet hunters, whether positive or negative. Good hunting! — *David J. Eicher*



Pluto's Path Across the Sky

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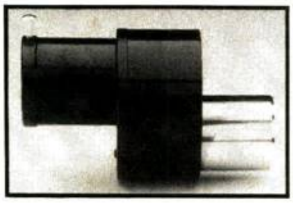
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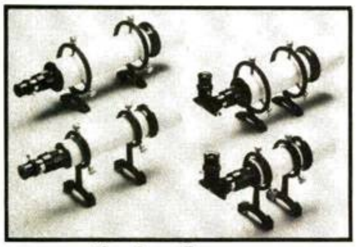
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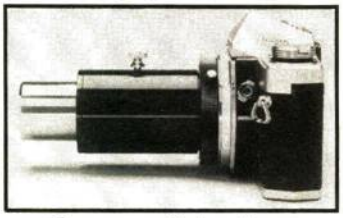
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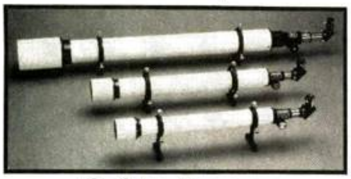
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ASTRONOMY
Reviews

Project Space Station
Brian O'Leary
160 pages, hardcover, $12.95
Stackpole Books (1983)

There is a debate going on between Congress and NASA: the space agency is itching to begin work on a new space station project, but the legislature, which holds NASA's purse strings, is unwilling to fund a multi-billion dollar project it sees as neither necessary or desirable.

According to author Brian O'Leary, a former astronaut and present day space-technology prophet, all this debate is academic. In his new book, *Project Space Station*, O'Leary claims that space stations are a part of our future. The only questions that remain are "how, when, and by whom."

O'Leary has not written a nuts-and-bolts book detailing the "final design, a set of orbits, and an evolutionary plan for a space station." Instead, *Project Space Station* is a visionary work that examines what a space station could mean to the future of mankind. While O'Leary discusses in some detail the technical, social, and political forces involved in initiating a major space station program, it is his very non-technical view of the future — one filled with Earth-orbiting space stations — that is the primary theme of the book.

Unfortunately, *Project Space Station* is a less than successful effort. Instead of a cohesive book tying together O'Leary's vision of the future with the many political and social factors involved in getting a space station program off the ground, the reader is treated to a loosely organized jumble of data. O'Leary wanders from subject to subject to an extent that his writing style could almost be described as stream-of-consciousness. For example, in one chapter the topic is the European Spacelab, which was launched on STS-9 last November. But in mid-course, O'Leary suddenly turns the discussion to how NASA's technical jargon hides the real excitement of space travel. The chapter concludes with an overview of NASA's proposed space station, the Space Operations Center!

The book also suffers from the author's continual digressions. Peppering *Project Space Station* with numerous personal references, O'Leary is undoubtedly trying to add a human touch to the book. But his asides do not add; they only detract. I am not interested in a speech he made to a bunch of students in Europe, or how the space station research group at Rockwell International lost their aesthetically pleasing offices and were shuffled to the factory-like environment at the Downey plant. And frankly, I just don't care that O'Leary's Ford van broke down after he listened to President Reagan's July 4, 1982 speech.

In spite of these criticisms, *Project Space Station* does have some redeeming qualities. There are numerous nuggets to be found in the book — but it takes a lot of sifting to find them.

For example, in the first section of the book, O'Leary discusses the findings, technical as well as political, of NASA funded space station research projects. This is interesting stuff to anyone who wants to know how a major space program gets off the ground. But this assortment of insider's information — and there is a lot of it — is so badly organized that the reader is more likely to be overwhelmed than enlightened.

The author also touches on an important point when he mentions the unpredictable benefits which will be realized from space stations. Though he describes four likely projects — space telescopes, asteroid mining, power satellites, large communication satellites — which will be part of what he calls a "renaissance in space," O'Leary stresses that there are literally hundreds of benefits we cannot anticipate. These serendipitous benefits, visible only to the visionary eye, are the real reason for investing billions of dollars in a space station program.

The main theme of the book is O'Leary's vision of how space stations will transform humankind and this, unfortunately, is where he is likely to lose most of his readers. According to O'Leary, a space station could become home to an "enlightened community of people who seek to experience the joy and freedom of themselves in their exotic new environment, who view the beauty of the Earth beneath them with a sense of the oneness of mankind, who are on a quest for new visions."

To me, this utopian optimism, so often the hallmark of an incurable technophile, calls the validity of the book into question. And it is not just references to the "Aquarian revolution" that cause me to wonder about O'Leary's reasoning. Earlier in the book he asks if it was right to spend billions of dollars to go to the Moon? "Of course it was because it felt good at the time. . . . It was an emotional decision and therefore the right decision." After this statement, and others of the same kind, *Project Space Station* starts to lose its credibility.

With this book, O'Leary had an opportunity to write a unique and important work. By addressing the many social and political features — the whys and hows — of a space station project, the author raised issues and presented ideas not found in most books on future space technology. Unfortunately *Project Space Station* is a largely disappointing effort. Though there are some interesting and even important ideas in the book, they are lost in the disjointed text and the author's uncritical idealism. *Robert G. Nichols.*

Relativistic Astrophysics, Volume 2, The Structure and Evolution of the Universe
Ya. B. Zel'dovich and I.D. Novikov
718 pages, hardcover, $65.00
University of Chicago Press (1983)

The title says it all — this book discusses everything from the expansion and geometrical structure of the universe to gravitational instabilities and anisotropic cosmology. Editor Gary Steigman describes the authors' role in modern cosmology as being "midwives in its birth" and "shepherds of its more recent growth to majority."

The book is intended for a professional audience, and represents the second volume of Zel'dovich and Novikov's monograph *Relativistic Astrophysics, Volume 1, Stars and Relativity*, which was published in 1971.

Catalog of Cometary Orbits

Brian G. Marsden
96 pages, paperback, $10
Enslow (1983)

The Catalog of Cometary Orbits lists orbital elements for 1,109 cometary apparitions dating back to 240 B.C., the first documented showing of Halley's Comet. In addition to orbital elements, the book supplies a variety of other data useful for someone interested in comets.

Realm of the Long Eyes

James E. Kloeppel
136 pages, paperback, $9.50 postpaid
Univelt Inc. (1983)
[publisher's address: Box 28130,
San Diego, CA 92128]

Subtitled *A Brief History of Kitt Peak National Observatory*, this book details events, telescopes, and people involved with Kitt Peak from an initial planning meeting held at Lowell Observatory in 1953, all the way to the present. It includes 96 photographs and illustrations of telescopes and astronomers on the mountain.

Astronomy From Space: Sputnik to Space Telescope

James Cornell and
Paul Gorenstein, editors
248 pages, hardcover, $17.50
MIT Press (1983)

Located along that continuum of events that we label "time" are an infinite number of discrete points. Some are of little importance, while others have significantly altered the course of human history: harnessing the atom, discovering the wheel, the establishment of the Copernican theory, the invention of the telescope, and so on.

Here and there on the continuum are periods when highly significant events have taken place concurrently, or nearly so. Such times are usually thought of as interesting periods in which to live — and the message of *Astronomy From Space* is that we are *living* in just such a high-interest, complex, and scientifically revolutionary period.

What is space astronomy? According to Harvard astronomer George Field it is "remote observation of astronomical objects from Earth orbit above the atmosphere." Until a few years ago, the bulk of our astronomical knowledge came to Earth through a very narrow band of the electromagnetic spectrum — the visual. Visual-wavelength information is detectable only after it makes its way through our turbid and soupy atmosphere, and it often arrives diluted and distorted.

In the late 1940s, captured German rockets, and their cousins developed in the U.S., made data collection from space a reality for the first time. This opened the way for orbital instruments capable of detecting a much wider range of radiation than just the visual. As instruments improved, the number of "windows" on the universe increased and the era of space astronomy began.

Astronomy From Space comprises eight lectures originally sponsored by the Harvard-Smithsonian Center for Astrophysics, the Hayden Planetarium in Boston, and the Lowell Institute; it describes what we have learned about the universe by looking through the non-visual windows — gamma-ray, X-ray, infrared, ultraviolet, and radio. In addition to the eight lectures, the book includes an introductory chapter and a final wrap-up section.

A lucid explanation of the dynamics of terrestrial geology opens the volume and lays a foundation for comparing the surface dynamics of the Moon, Mars, Venus, and Mercury. It notes the similarity of earthly geological processes to those of the planets, and draws conclusions. This chapter, as well as the others, includes several black-and-white photographs and line drawings. The next three chapters deal primarily with exploration of the Moon, the Voyager project, and recently acquired knowledge of the Sun — all of substantial interest.

But it isn't until chapter 6, "The Ultraviolet Sky," that the book really begins to live up to its title. There the reader gets a look at solar system objects, the interstellar medium, globular star clusters, and galaxies as they appear in the ultraviolet region of the spectrum. An X-ray portrait of our own Galaxy comes next, followed by a description of several strong X-ray sources, which features a non-technical overview of one of the more fascinating astronomical phenomena, the X-ray burster.

X-ray astronomy hints at the presence of a colossal black hole, possibly a million times more massive than the Sun, lurking at the center of our Galaxy. Would some cosmic eye trained on our Galaxy perhaps see a vast whirlpool of stars slowly and inexorably spiraling into its clutches? Advances in galactic X-ray astronomy will seek to unravel this and other mysteries of the Galaxy.

The last two chapters, "X-Rays Beyond the Milky Way" and "The Future of Space Astronomy," examine the physical processes that can produce X-rays. The reader is also introduced to several projects that will greatly enhance the role of space astronomy, such as the Space Telescope, the Far Ultraviolet Spectrograph, the Advanced X-Ray Explorer, and a Large Deployable Reflector. Also on the drawing boards is a Very-Long Baseline Array, which will employ an orbiting antenna and which is expected to obtain radio images far more sharply resolved than is possible at present. Additionally, plans for several large ground-based optical telescopes are explored.

The entire volume is pulled together in an epilogue that summarizes the new knowledge acquired through space astronomy, including late advances in global weather forecasting, a new look at the Van Allen radiation belts, and an update on the solar wind.

Our ability to see the universe with new eyes has already produced a remarkable amount of new knowledge; this does not, however, mean an eventual obsolescence of ground-based observation. Indeed, given the present cost of putting a payload into orbit via the Shuttle (over $500 a pound), orbital instruments will remain relatively few, and ground-based observatories still have long lifetimes ahead of them.

We are living in a renaissance-like period for astronomy, and anyone interested in what has happened over the past 25 years should read this neatly compiled, timely collection. *Gail O. Clark.*

Darwin's Universe

Charles R. Pellegrino and Jesse A. Stoff
208 pages, hardcover, $18.95
Van Nostrand Reinhold (1983)

Darwin's Universe is a hard book to classify — it mixes astronomy and biology in a unique way and comes up with some unusual results. One of the more interesting concepts propounded in it is that life forms or their remains may yet be found under the surfaces of various planets, asteroids, and moons in the solar system. It is there, the authors feel, that more temperate zones between icy surfaces and molten cores could have existed long enough for life to have developed into a recognizable form. Authors Pellegrino and Stoff, who are apparently well-qualified and certainly enthusiastic, also speculate on the curious microstructures found in carbonaceous chondrite meteorites.

Other interesting ideas include the thought that the Sun and its nearest solar neighbor, Alpha Centauri, were born in the same protostar nebula; that the best chance for life near Mars may be inside Phobos, one of its moons; and that the extinction of the dinosaurs may have *already been well underway* before the impact of an asteroid spread a dark cloud into the Earth's atmosphere and caused serious climatic changes. Though these ideas are not wildly radical, they *are* out of the ordinary.

In outline, the book begins with a discussion of the Big Bang and the early history of the universe, followed by the creation of stars, their development by means of novae and supernovae, and the distribution of the chemical elements throughout the universe. This forms a background for introducing the reader to studies on the first protocells. At this point, however, many non-biologist readers will rapidly bog down in a rather technical discussion of genetic evolution. Although it may be absorbing to the biologist and is undoubtedly relevant to the topic, it is not for the layman. This section needs better editing or perhaps a rewrite.

The rest of the book discusses likely footholds for life in the solar system, and concludes by elaborating on ways terrestrial evolution may have been affected by "outside" influences.

The book boasts a good bibliography — a somewhat rare feature for works of this size. The text is also illustrated with well-captioned and informative photos and drawings. But I suspect that many potential buyers will feel that nearly $20 is too steep a price for just 191 pages of text. There are other problems, too, though they deal more with style than content. The authors have an irritating habit of scattering parenthetical asides throughout their text. In fact, it is difficult to find a single page that doesn't have at least one of them.

But despite these flaws, *Darwin's Universe* explains enough about the development of life in the universe, in light of recent biological and physical discoveries, to make it very worthwhile. Besides, where else can you find one book that attempts to tie together such seemingly diverse sciences as meteorology, biology, physics, geology, chemistry, and astronomy — and explains how they can interact to develop life? *Ray Grasshoff.*

Modern Observational Techniques for Comets

Jet Propulsion Laboratory
319 pages, paperback, $16
U.S. Government Printing Office (1981)
[stock number 033-000-00835-0]

Derived from a NASA-sponsored conference at Goddard Space Flight Center, this book reprints the papers given at the meeting. The topics covered include photometry, astrometry, spectroscopy, radio observations, imaging of coma and tail, and others. The emphasis of most papers lies on preparations for the upcoming Comet Halley encounter. Although the collection is aimed at the professional astronomer, amateurs (especially Halley Watch members) will want at least to examine a copy of the book in the library.

1984 Yearbook of Astronomy

Patrick Moore, ed.
205 pages, softcover, $9.95
W.W. Norton & Co. (1983)

This book contains a month-by-month summary of celestial events occurring this year, a set of small naked-eye star maps, and a section of articles by several authors on such topics as the new British telescope on the Canary Islands, Europa's atmosphere, the center of the Milky Way, and probing the Galaxy with RR Lyrae stars.

The First 25 Years in Space

Allan A. Needell, ed.
152 pages, hardcover, $12.50
Smithsonian Institution Press (1983)

The Space Age began on October 4, 1957, and many symposia were held to mark its 25th anniversary. One such was given by the Smithsonian; this volume presents the results. The book is organized around three main sections: "Motivations for Space Activity," "Practical Dimensions of Space," and "Science and Space." Under each of these headings, one author discusses a certain subject — "Motivations for the Space Program" was Harvey Brooks's topic, for example — and three others follow with comments. Each section then concludes with the transcript of a general discussion.

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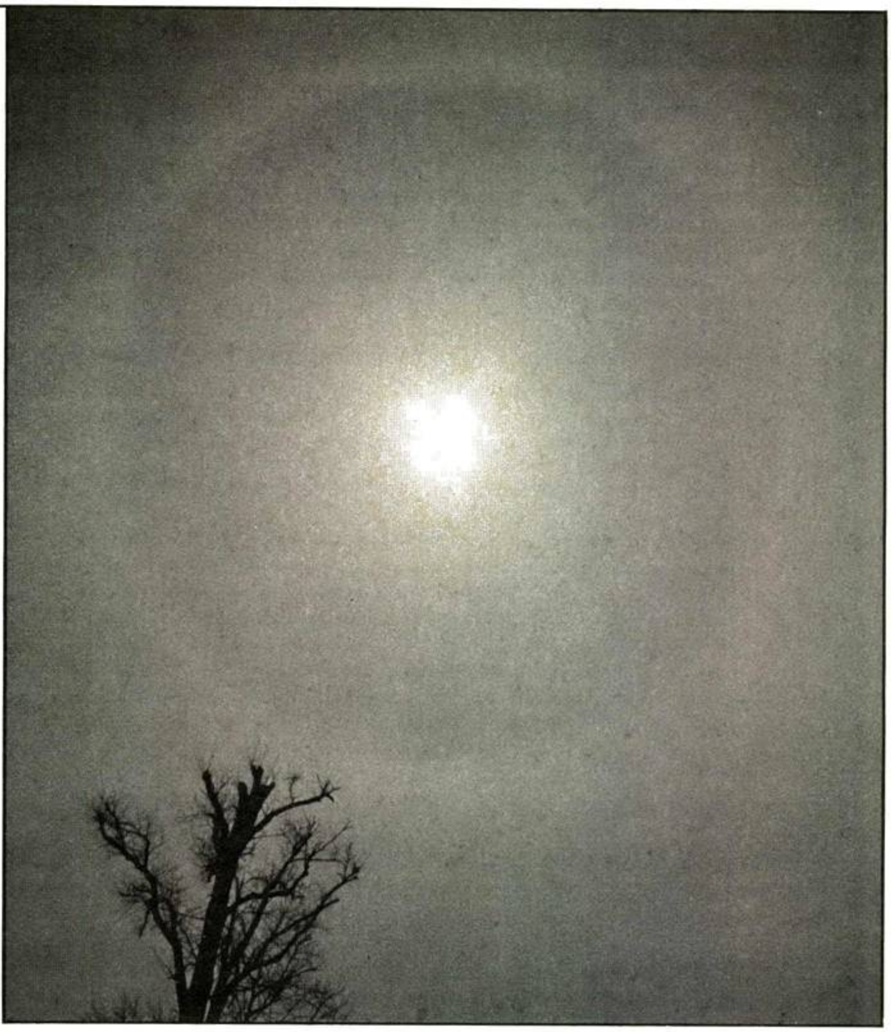
Eye on the Sky

Mercury's Fleeting Show

by Fred Schaaf



James H. Kerr used his 50mm f/1.8 lens and camera loaded with Tri-X to photograph an ice halo surrounding the gleaming Full Moon. The halo is caused by the refraction of sunlight in ice crystals high in the Earth's atmosphere.

Late in 1982, Jacques Guertin photographed the dawn sky including the waning crescent Moon 4° north of Mercury, which shone at magnitude 0. During the evening hours early this month, tiny orange Mercury makes its finest appearance of the year.

The Wanderers

This year April evenings offer a splendid showing of six outer planets, three of which are naked-eye objects. All of them are brightening and moving retrograde (westward) by month's end; all approach oppositions that fall between mid-April (Pluto) and late June (Jupiter). Although one inner planet, Venus, is lost in the dawn sky, Mercury completes its best apparition of the year in the evening sky.

Mercury normally presents its best apparition for north temperate latitudes around this time of year. The planet's smallest evening elongation for 1984, which occurs on the American evening of April 2, is only 19.1°. From 40° north latitude, however, Mercury has almost the same azimuth as the Sun 30 minutes after sunset. In other words, almost all of Mercury's elongation is converted into altitude.

Be sure to observe the planet in the early days of the month, though. Mercury reaches inferior conjunction on the 22nd and will hardly be visible at all for most of us when it pokes just a bit higher into the morning sky next month. By April 10 Mercury has lost just a few degrees of altitude; but soon afterward it plunges and fades, to make matters worse. Its magnitude drops from zero to first to second during the first, second, and third weeks of April.

While Mercury fades in evening twilight, far brighter **Venus** is already lost in the morning twilight. The angle of the ecliptic to the east horizon at north temperate latitudes is unfavorable in the predawn sky of spring. Although its elongation from the Sun ranges from 20° to 13° during April, Venus will elude most of us. The situation is worsened by the fact that Venus is at its greatest latitude south of the ecliptic on April 15. And Venus even hits a minimum of brightness in April, reaching a magnitude of −3.3.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

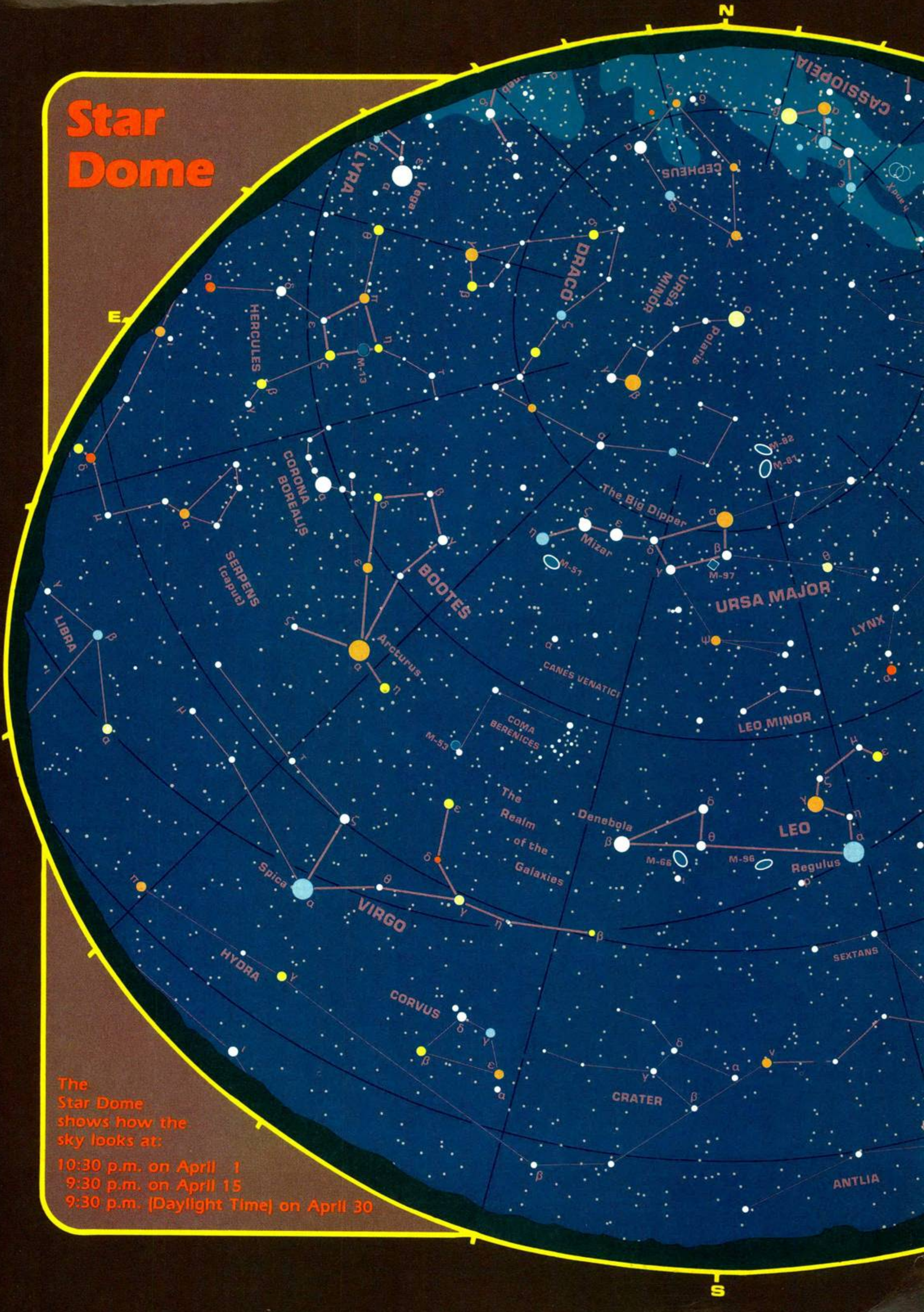
The usually spectacular planet will not become easily visible in North America or Europe again until the end of July. For many observers this is the longest period during which Venus remains out of sight, making 1984 a terrible year for Venus observers. A close conjunction of Mercury and Venus on the 29th will be impossible to view, but nice conjunctions involving Venus occur late in the year, after the beacon once again climbs out of the scattered sunlight.

But not to worry — this month is excellent for viewing all the other planets. The first visible in the evening are Saturn and Mars; look for them on either side of the large, skewed rectangle that forms the constellation Libra the Scales. On the 16th and 17th, a waning gibbous Moon looms near Saturn and Mars, and occultations will be visible in some parts of the southern hemisphere.

While the brightness of Mars easily tips the scales in its favor, **Saturn** is still an impressively bright object. During April, the mighty ringed planet retrogrades just a few degrees north of relatively feeble Alpha (α) Librae. This year's opposition takes place on May 3, but by late April Saturn rises early in the evening twilight and shines at magnitude 0.3. Compare the planet's gold hue with that of just slightly brighter Capella in the northwest. Arcturus is another convenient, though somewhat brighter and higher, object for color comparison.

If Mercury is rapidly fading, **Mars** does just the opposite. The red planet brightens from −0.5 to −1.0 by mid-month, and then to a spectacular −1.4 by month's end. Since Sirius becomes lost in afterglow during April, no point of light rivals Mars until Jupiter rises late in the evening. Yet

Star Dome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URSA MINOR
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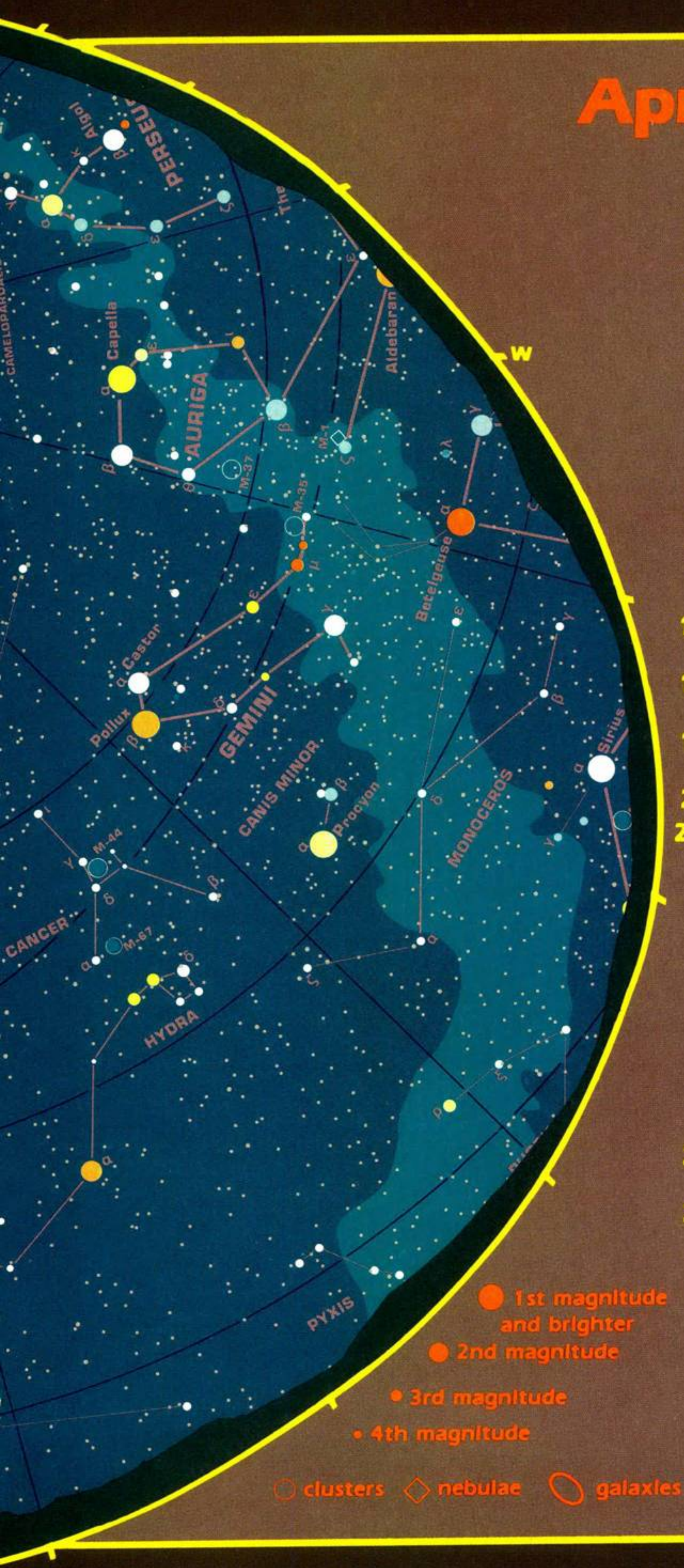
SERPENS (caput)
LIBRA
BOOTES
Arcturus
M-82
M-81
The Big Dipper
Mizar
M-51
M-97
URSA MAJOR
LYNX
CANES VENATICI
COMA BERENICES
M-53
LEO MINOR
The Realm of the Galaxies
Denebola
M-66
M-96
LEO
Regulus
Spica
VIRGO
SEXTANS
HYDRA
CORVUS
CRATER
ANTLIA

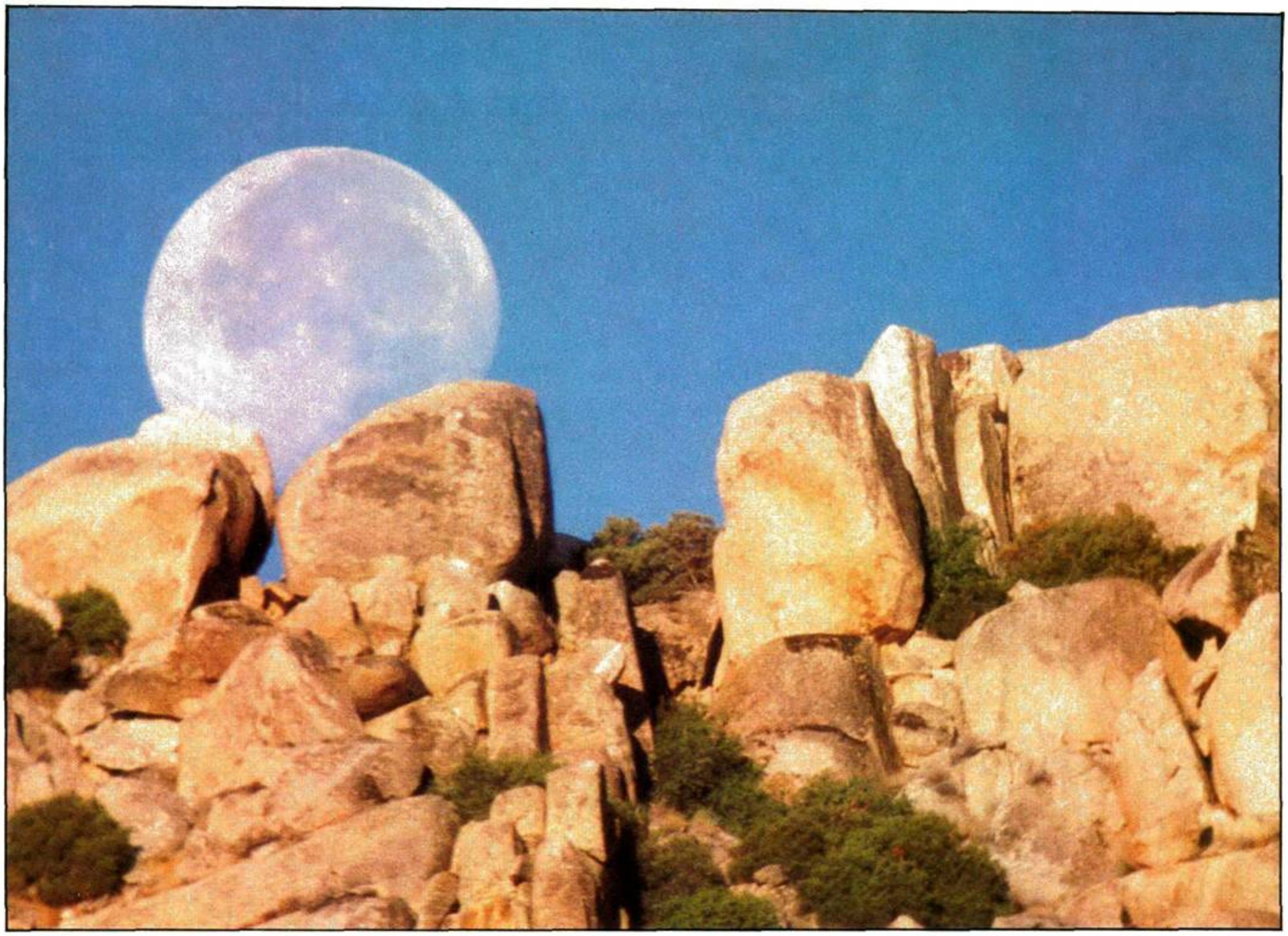
The Star Dome shows how the sky looks at:

10:30 p.m. on April 1
9:30 p.m. on April 15
9:30 p.m. (Daylight Time) on April 30


Algol
PERSEUS
Capella
AURIGA
M-37
M-35
M-1
Aldebaran
W
Betelgeuse
Castor
Pollux
GEMINI
CANIS MINOR
Procyon
MONOCEROS
Sirius
M-44
CANCER
M-67
HYDRA
PYXIS
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

April Sky Almanac

1st	New Moon occurs at 7:10 a.m. EST.
2nd	Neptune is stationary in right ascension.
3rd	Mercury is at greatest eastern elongation and at peak visibility in the evening sky. This elongation offers the best views of Mercury you'll have this year.
5th	Mars is stationary in right ascension.
8th	First Quarter Moon occurs at 11:51 p.m. EST.
12th	Mercury is stationary in right ascension.
14th	The Moon is at perigee at 00:39 a.m. EST: 224,020 miles.
15th	The Moon is Full at 2:11 p.m. EST.
20th	Pluto is at opposition.
22nd	The early morning hours today mark the peak of activity for the Lyrid meteor shower. Look for about 15 per hour coming from the northeastern sky — though the late-rising Moon will hamper your observations by lightening the sky. Also today: Mercury is at inferior conjunction, and Last Quarter Moon occurs at 7:26 p.m. EST.
26th	The Moon is at apogee at 1:47 a.m. EST: 251,893 miles.
29th	Jupiter is stationary in right ascension.



Jerry Schad of San Diego used a telephoto lens and 400 ASA emulsion for this short exposure of the nearly Full Moon setting over barren rocks in the California desert. Most of the lunar maria and a few large craters are clearly visible.

Mars brightens still more before reaching opposition on May 11.

Mars' motion is fascinating this month, as it halts and begins to retrograde on the evening of April 4 and, as always, spends less time moving westward than the gas giants. Usually a planet traces a retrograde loop in the sky, but when it is crossing the ecliptic (at an *ascending* or *descending node* of its orbit) the pattern is a flattened S-shaped loop. Mars is one of three outer planets to cross the ecliptic this year, and it does so at a special time. We'll look at this further next month.

Uranus, a naked-eye object, and **Neptune**, visible in binoculars, float in Ophiuchus and Sagittarius respectively. Both rise several hours after Mars. But the final outer planet to appear is **Jupiter**, which begins to retrograde this month. When it halts at a point northeast of the Teapot in Sagittarius on April 29, Jupiter's magnitude is −2.0. Jupiter bears close observation this month because of its progress past two fifth-magnitude stars, Nu^1 (ν^1) and Nu^2 (ν^2) Sagittarii. At 12:10 UT on April 8, the planet lies a mere 6 arc-minutes north of Nu^1; at 4:41 UT on April 12, Jupiter is just 2.5 arc-minutes north of Nu^2. Through a suitably large pair of binoculars, Jupiter may appear to have collected some extra Galilean satellites. Just wait until next month, though. In May, Jupiter retrogrades between the two, its center missing Nu^2 by just 39 arc-seconds!

While the Lyrid meteors are hampered by the bright Moon, another small solar system body deserves special note. Minor planet **Vesta** is only 9 arc-minutes south of sixth-magnitude star 5 Geminorum on the American evening of April 25. But the really marvelous conjunction occurs on the night of April 23-24, when Vesta passes right in front of the large fifth-magnitude cluster M-35. The brightest cluster member is magnitude 7.6; Vesta will be somewhat fainter. Vesta is also the only one of the "Big Four" asteroids to pass through the Beehive cluster in our time.

The Starry Sky

On spring evenings, a most popular asterism is at its highest. The Big Dipper, which is completely circumpolar north of about 40° north latitude, arcs upward, carrying its many faint galaxies along with a handful of bright blue-white stars. The Big Dipper makes for a fine directional measuring rod and timekeeper. The stars composing the bowl's outer edge are **Dubhe** and **Merek**, the famous "pointer stars" that mark the direction to **Polaris**. The distance between the two Pointers is a convenient 5°, and across the top of the Dipper (from Dubhe to the handle-joint, **Megrez**) is 10°.

When held out at arm's length, the average person's fist subtends an arc of about 10° and when outstretched, the distance from forefinger to little finger is about 15°. We should remember, however, that even though large hands tend to go with long arms, there is considerable variation. Learning to use your hands to measure angles in the heavens is a good idea, but you should first "calibrate" your hand with the known dimensions of the Big Dipper. How long is the entire Big Dipper, from Dubhe to **Alkaid**, the star at the end of the handle? The answer is 25°, five times the length of the side of the bowl marked by the pointers. The shapely dipper may be large, but it is not quite large enough to fill the gap between Dubhe and Polaris.

Curiously, a modest estimation of the greatest length of Comet Halley's tail in 1986 is 25°, about the overall length of the Big Dipper. Keep that in mind when you're out observing the pointer stars.

The Big Dipper is only a fraction of the officially recognized constellation **Ursa Major**. This Great Bear has an unnaturally long tail, represented by the stars of the Big Dipper's handle, and the Great Bear's length from snout to tail-tip is almost twice the length of the Big Dipper alone. His body and legs are depicted by stars — some of which are rather bright — south and southwest of the Big Dipper. Three close pairs of stars make three paws of Ursa Major, and were known by the early Arabs as the Three Leaps of the Gazelle.

Another use of the Big Dipper's handle is extending it so that it "arcs to Arcturus." **Arcturus** is the zero-magnitude orange star now so solitary and prominent in the northeast. A line drawn through the bottom of the Big Dipper's bowl — which is now the highest part of the figure in the north — also points roughly to the star. Arcturus belongs to the fairly dim constellation **Bootes** the Herdsman. Just ahead of Bootes, literally at the heels of Ursa Major, is **Canes Venatici**, the Hunting Dogs. Its two major stars are called **Cor Caroli** and **Chara**, and pass almost directly overhead at 40° north latitude.

After making the arc to Arcturus, we can — as one tradition suggests — "drive a spike to Spica." A straight line does indeed point us to first magnitude **Spica** in Virgo, which is being pursued this spring by the far brighter Saturn and Mars. Most of the sky is free of first-magnitude stars now. **Aldebaran**, **Rigel**, **Betelgeuse** and **Sirius** sink below the western horizon early these evenings, with **Capella**, **Pollux**, **Castor**, and **Procyon** following shortly afterward. **Vega** and **Deneb**, summer stars, are nudging over the horizon in the northeast. Across more than five hours of right ascension, viewers at 40° north latitude can see only one first-magnitude star. And it is the faintest of the "bright finder stars" — **Regulus**.

Regulus is made more prominent by two other aspects of its location. First of all, it marks the heart of **Leo** the Lion. The celestial king of beasts is one of the most impressive constellations of any season, featuring several second-magnitude stars arranged in a striking pattern. Secondly, Regulus lies close to the ecliptic and therefore is often found near the Moon and planets. Surrounding Leo are a number of faint constellations. To his west, **Cancer** the Crab is still well-placed for observation, as is the head of **Hydra** the Serpent. The heart of Hydra, **Alphard**, is an orange second-magnitude gem in solitude. The body of Hydra stretches across the meridian in a faint wandering until it loops down under dim **Crater** the Cup and one more rather prominent constellation — the compact **Corvus** the Crow, now in the southeast.

Ursa Major, the Great Bear, dominates the northern skies during spring months. Its most commanding feature is the giant asterism known as the Big Dipper, here visible as it begins its slow upswing in the northeast. Photo by Stephen Walther.

Skylore

How can a single fourth-magnitude star be the object of much lore? That is the case with Alcor, the star 80 Ursae Majoris. Alcor is a naked-eye companion of Mizar, the star at the bend in the Big Dipper's handle. It is the little glimmer the unaided eye can see just beside the much brighter glow of Mizar in reasonably good conditions.

How difficult is it to perceive Alcor with the naked eye? The 4.0 magnitude star is 11.8 arc-minutes from 2.4 magnitude Mizar. Most of us agree that seeing Alcor is not difficult if skies are fairly good, but this is an interesting test (especially under different conditions) for astronomy clubs.

One of the Arabic names for Alcor in the Middle Ages was, in fact, Al Sadak, "The Test." Does this mean that the dwellers under desert skies cleaner than those of our days actually thought seeing Alcor a test of extremely acute eyesight? T.W. Webb and others have suggested that Alcor may have been fainter or slightly closer to Mizar back then, but neither is likely. (Especially the latter — Mizar, itself a pair, and Alcor, travel through space together about one quarter light-year apart but do not revolve about each other.)

There is uncertainty about the derivation of the star's name. Admiral Smyth suggested that the name was derived from Al Jaun or Al-jat, a "courser" or "rider," and certainly there have been legends describing the star in these terms. In England down through the centuries, Mizar and Alcor have been known as Horse and Rider and Alcor itself as Jack on the Middle Horse (three horses being the three stars of the Dipper's handle, sometimes said to be following a funeral Bier).

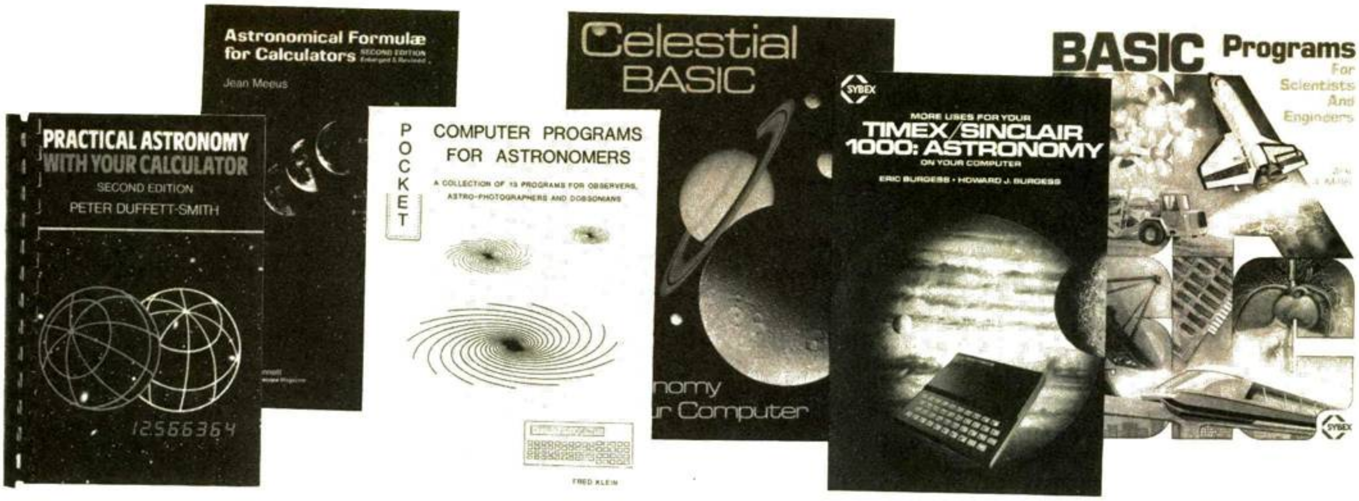
There is also the tale of Hans Dumken (Hans the Thumbkin) from Germany. According to this tale, Hans was a wagoner who gave a poor wayfarer a ride on this wagon. When the wayfarer turned out to be Christ, who offered Hans the kingdom of heaven as a reward, Hans instead asked for the right to drive his wagon forever among the stars. R.H. Allen says the Hungarians have a somewhat similar tale, and call the star Gontzol.

But a 20th century skywatcher who was familiar with Arabic and researched star names had another idea about the name Alcor. George A. Davis, Jr. believed the star's name is derived from the Persian "Khwar" (with Arabic article *al-* prefixed), which might be translated as "abandoned," or "friendless" or "abject." This is similar to another popular medieval Arabic title for the star, Al Suha, "The Lost One" or "The Forgotten One."

Alcor was the object of proverbs among the Arabs of the Middle Ages. The Arabs opposed Suhel (Canopus) to Suha (Alcor), as representing the most conspicuous (or nearly most conspicuous) and the least conspicuous stars of the heavens. They also spoke of people who could see trivialities but not great general truths as capable of noticing Alcor but not the Full Moon. Smyth tells us that "this little fellow" (Alcor) was called upon by the Arabs to guard them against scorpions and snakes — creatures which conceal themselves.

According to R.H. Allen, Alcor was known to the ancient Greeks; there is an old story this star is the Lost Pleiad Electra and was called the Fox. He says a Latin title was Eques Stellula, the Little Starry Horseman. An old Chinese title was Fu Sing, a Supporting Star. Perhaps the most interesting account of Alcor's origin comes from Old Norse. In their mythology, the Norsemen tell that the friendly giant Orvandil got frostbite in one of his toes when he was on a long cold journey with Thor. The mighty Thor apparently wished to relieve his friend's agony and so snapped off the toe and flung it into heaven. It is thought that Orvandil was the constellation Orion after his death and that his toe was Alcor.

Gertrude and James Jobes state that the Mongols called the star Huitung Ot, Cold Star, because the Seven Robbers who were the Stars of the Big Dipper carried off one of the sisters of the southerly Pleiades cluster. This similarity of the Greek and Mongol versions is yet another strange link in the story of a Lost Pleiad, which seems to have sprung up in so many far corners of the world.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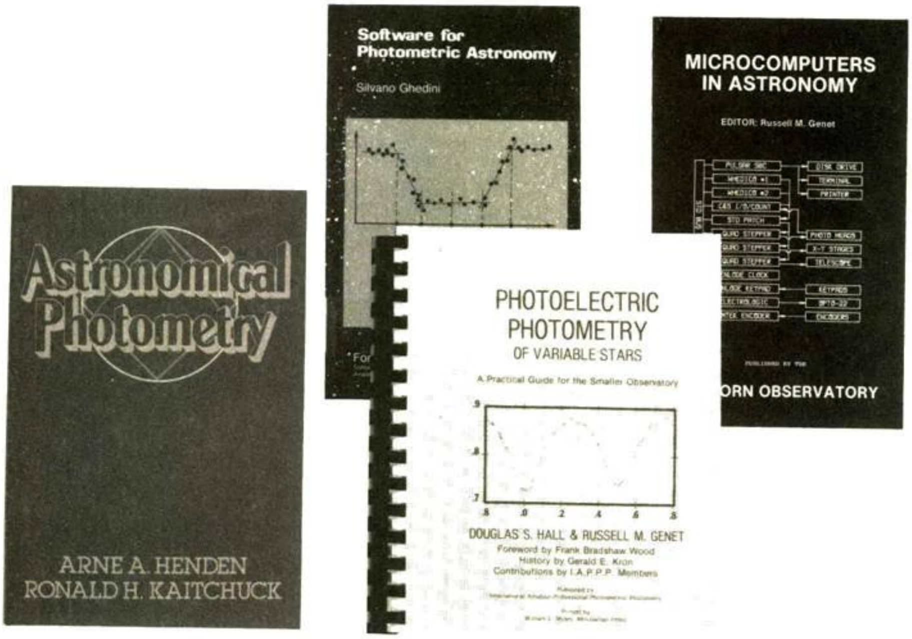
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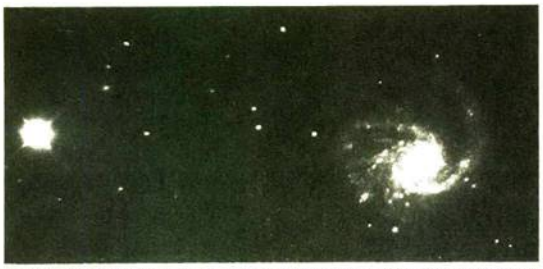

Spiral Galaxy NGC4254 (M-99) in Virgo. The spiral arms of this lovely 10th magnitude galaxy can be seen in larger aperture telescopes. Photo by Dr. Jack Marling using a LUMICON EASY-GUIDER and 2415 film sensitized in a LUMICON Model 300 HYPER-KIT. 40 minute exposure, 24"f/6.5 telescope.

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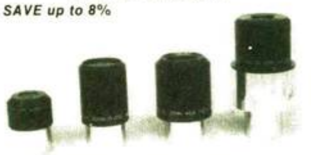

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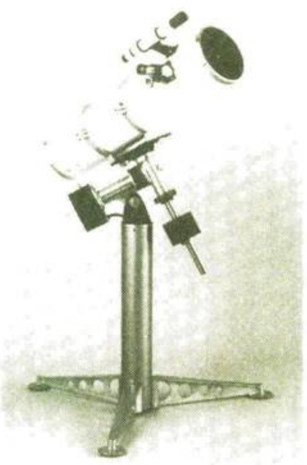

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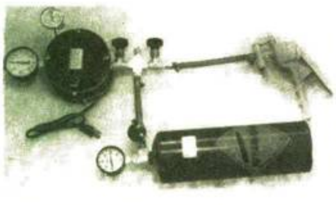

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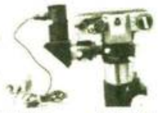

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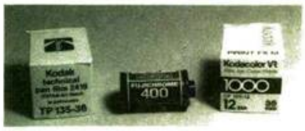

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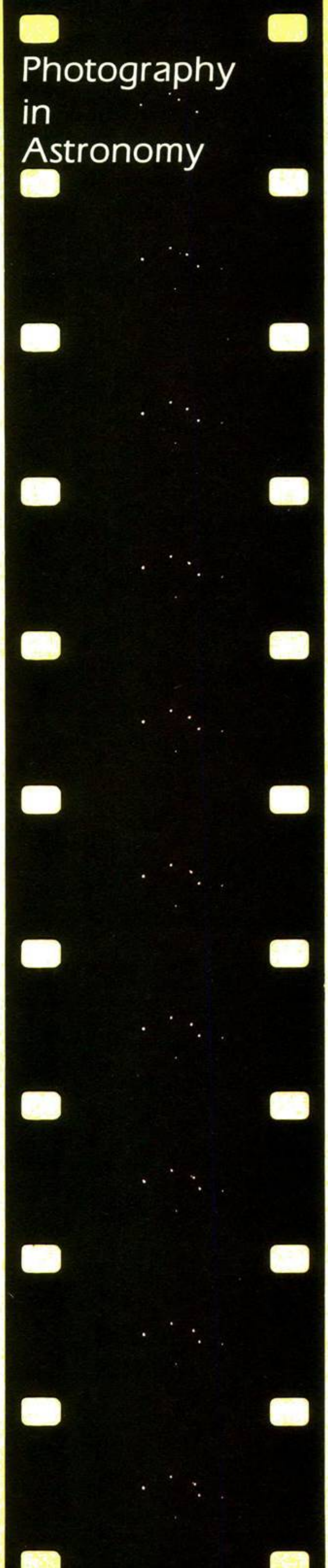
The Wanderers: A Movie of Planets in Motion

by
Carl Buzzard



Although the ancient Greeks weren't the first people to notice that some star-like bodies moved while others didn't, it is their word that we've adopted: planet is derived from the Greek *planetes*, which means "wanderer."

Planetary movements no longer occasion any mystery, but they are still intriguing to follow. Yet like the motion of an hour hand on a clock, they creep far too slowly to be casually observed over minutes, hours, or even a day or two. Except in rare cases of extremely close conjunctions, or when you observe at high telescopic magnification, it usually takes a week or so to notice changes.

Some years ago, I wondered why we should be prevented from watching this motion simply because of its slowness. Time-lapse photography has long been used to observe slow-moving events, so why not use it here as well?

The basic idea seemed simple: take photos every clear night of a particular region of sky that contained planets. Then cull them for the best shots and project them one at a time to the same scale and rephotograph them with a movie camera. When the film is completed, running it at normal speed ought to show the stars sitting still while the planets wander.

Well, as easy as the idea sounds, doing it turned out to be a little more complex than I'd anticipated. First of all, given that the Chicago area (where I live) isn't known for its long spells of crystal-clear nights, I knew I'd need some help. I contacted a friend, Paul Lorenz, who lives in Tucson, Arizona. By taking the photos from two widely separated locations, we sought to minimize the effects of local bad weather. For a subject, I chose the period from December 1, 1981, to mid-September, 1982, as it offered Mars, Jupiter, and Saturn moving back and forth very nicely in Virgo.

Once the project got organized and underway, the real beauty of it shone forth — it's all done with simple and readily available equipment. To take the constellation shots, we just needed ordinary 35mm cameras with matching 50mm lenses on tripods. On every clear night we each shot a single frame on Ektachrome 400 film. We kept the exposures to 20 to 25 seconds — this was about as long as you can go with an unguided shot using a 50mm lens. Longer exposures would have recorded more, but trailed images would have become annoying.

After nine and a half months, I collated all the slides and put them in proper sequence, pulling out the duplicates and other unusable pictures.

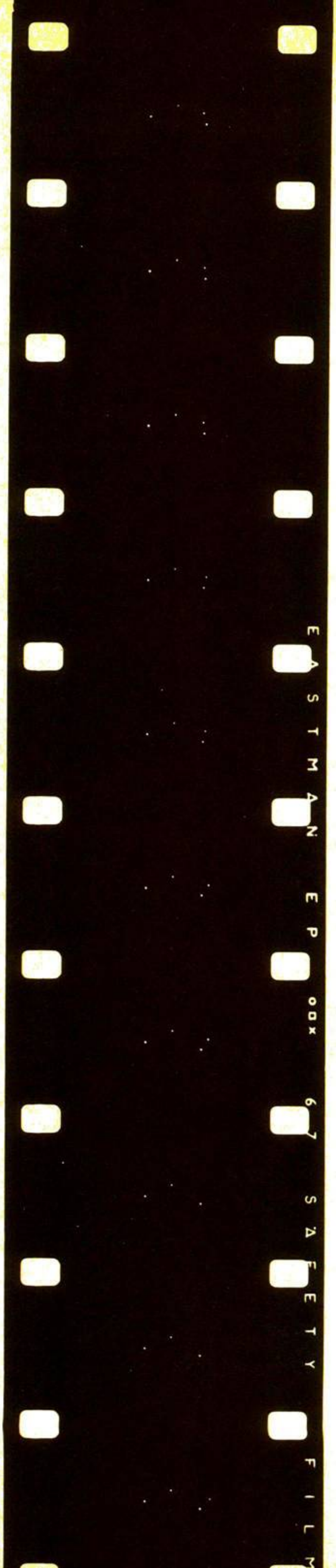
The principle of animating them went as follows: project a slide, line the background stars up with a predetermined standard plot, shoot a short section of movie film, change to the next slide, and repeat. I decided a "short section" would consist of two frames. This put each image on the screen for about 1/10 second — roughly the time it takes the human eye to blend a sequence of discrete images into an apparently unbroken flow.

So far, so good — but aligning the stellar background of each successive slide with the previous one meant building a projection stand with the necessary freedom of motion and establishing a "standard" for alignment.

The Projection Stand

Three types of motion were necessary — left/right, up/down, and rotation about the axis of the lens. Accordingly, I cooked up a three-layer design: a cradle holding the projector itself, a platform on which the cradle is mounted, and a base on which the feet of the platform rest and which in turn sits on a firm table top. The materials were scrap wood I had on hand and some common hardware-store stuff.

I needed about three square feet of ¼" plywood, about 15" of ¼" dowel rod, two 5" L-irons, about 18" of 1" x 2" wood stock, and some light wire. I mounted the platform on three feet for no-wobble stability. The two back feet were dowel rods angled out for strength. The front one was a long bolt, placed head down, giving about 6" of vertical movement. The three



feet all rested on the base, which I could slide left or right as necessary. For the actual vertical adjustment, I used an upside-down wing nut on the bolt, which passes through a drilled hole in the platform. A washer between the wing nut and the platform kept the rotation of the wing nut from "walking" the bolt around in the hole in the platform while I twisted the wing nut. I drilled a hole partway into the base for the head of the upside-down bolt to rest in.

The projector cradle is exactly that — a piece of plywood with sides that fit closely enough to keep the projector from slipping. Under the cradle runs the axle for rotating the projector parallel to the axis of the lens. In making it, the first task is to mount the two L-irons on the front and back of the platform. I spaced them so that the ¼" dowel rod passed through the top hole of each L-iron and stuck out a little. The bottom side of the cradle was stapled to the dowel. At this point, the whole cradle can rotate around the axle, parallel to the axis of the lens.

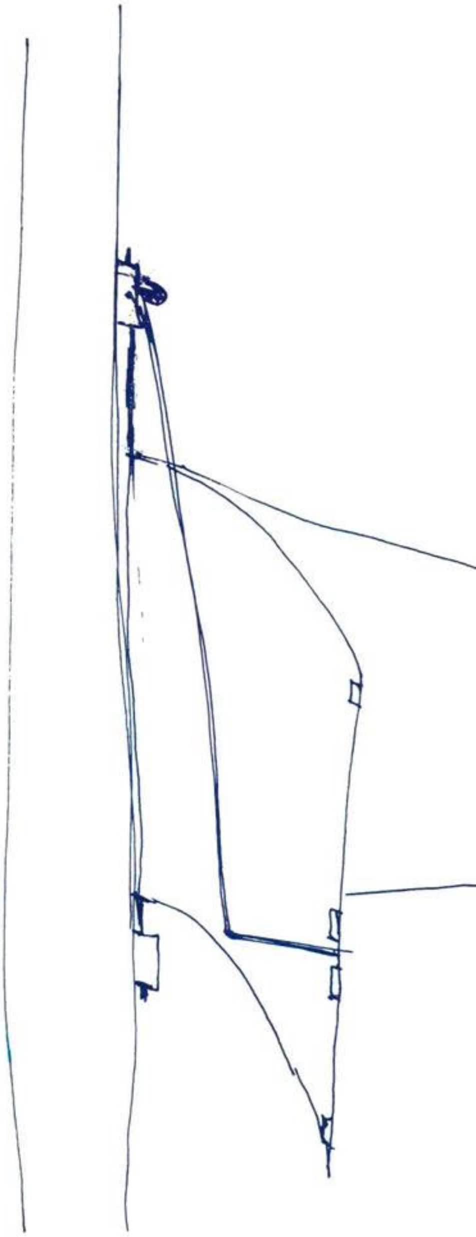
Take pains to place the dowel directly under the projector lens. This will keep the weight always on the same side of the axle, making control easier. Second, and more important, putting the dowel right under the lens keeps the subsequent horizontal and vertical readjustments to a minimum when you rotate the projector.

To control the rotation, I attached a vertical arm made from the 1" x 2" stock to one side of the base. Near the top of the arm I bored a 1" diameter hole through its long side. I then drilled a ¼" hole that passes through the large hole in the other direction and force-fit a length of ¼" dowel with a handle through the hole. This serves as a simple windlass and crank. (Mine relies on the friction of wood-on-wood, but if your projector is very heavy or if the fit is too loose, you'll need a set screw.) I then attached a pair of wires to the dowel-crank and fastened them under the far side of the cradle. It's important to make sure the side of the cradle comes high enough to keep the wires from interfering with the slide tray's operation. Twisting the crank lifts the other side of the cradle and rotates the projector approximately 60° about the axis. (You may also want to brace the upright arm, since it has to withstand a fairly hefty sideways pull from the weight of the projector.)

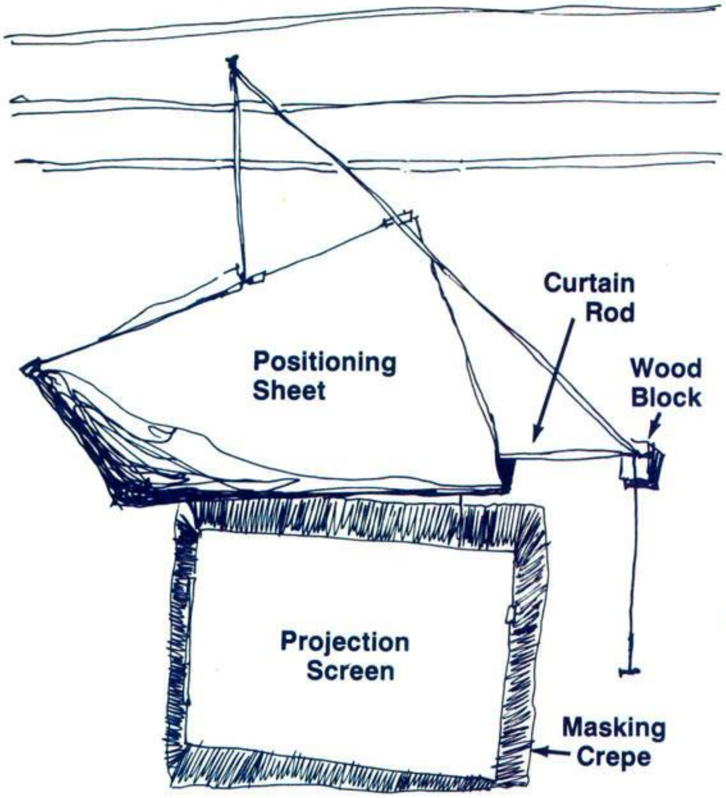
Lining Up the Photos

With the slide projector motions under control, I now needed something to align each slide with. The solution was a two-layer projection screen; you hand-plot the stars (in pencil) on the front sheet, while the second is kept clean for the actual filming. The second sheet is a piece of ¼" plywood attached to the wall and covered with a sheet of smooth white paper. This in turn is framed with a black border to clean up the edges of the field of view and to prevent stray light from scattering into it.

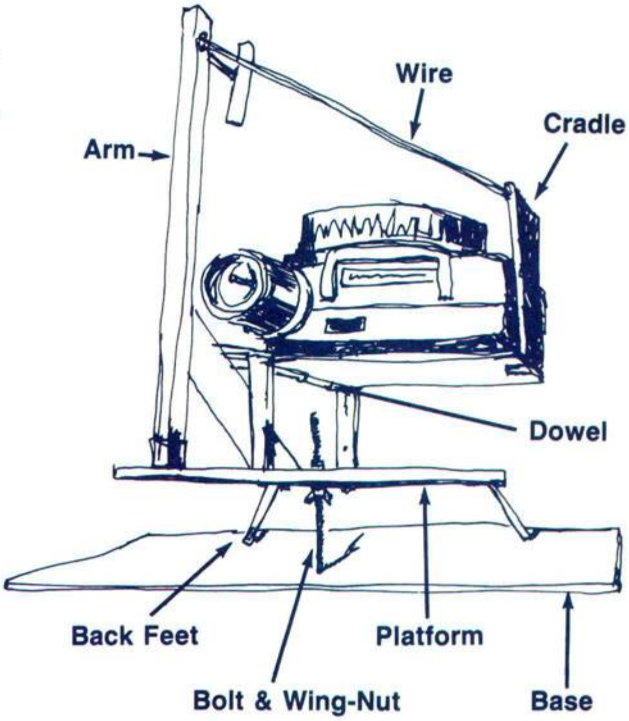
The Set-up for Animating Your Slides



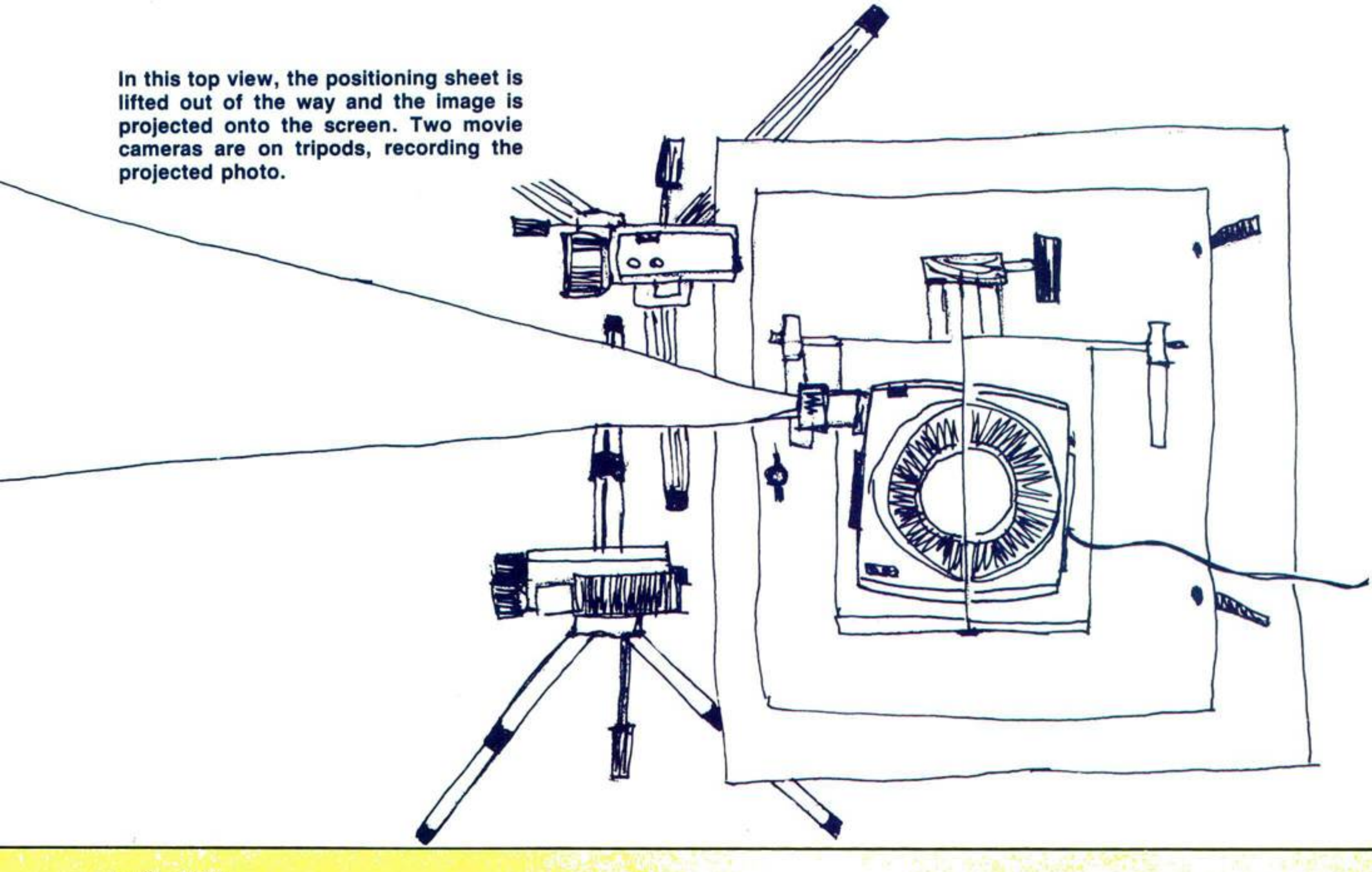
A pull on the string lifts the positioning sheet out of the way and lets the projected image fall on the screen.

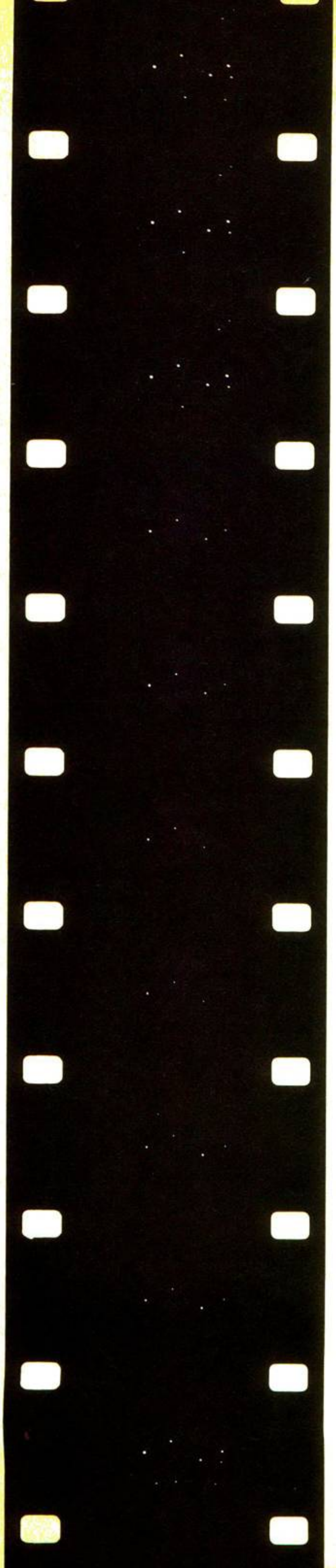

Curtain Rod
Positioning Sheet
Wood Block
Projection Screen
Masking Crepe

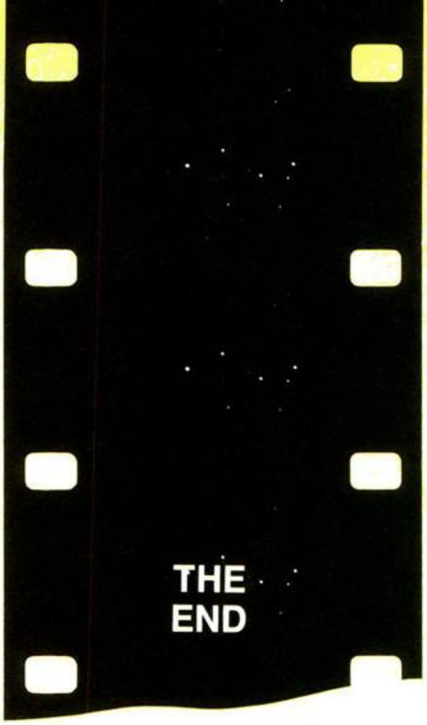
The base can swivel on the table top, the bolt controls the platform's up-and-down movement, and the wire rotates the cradle around the image axis.


Wire
Cradle
Arm
Dowel
Back Feet
Platform
Bolt & Wing-Nut
Base

In this top view, the positioning sheet is lifted out of the way and the image is projected onto the screen. Two movie cameras are on tripods, recording the projected photo.







On the wall beside the second sheet I epoxied two wood blocks slightly above the second sheet's upper edge. Across the two wooden blocks I clamped an old curtain rod and taped a large sheet of white paper along its full width. This became my front screen, or position plotter. Next, I taped a thin strip of wood across the bottom of this sheet for stiffness and ran a string from the wood up to a bent nail overhead and back down. An old lag bolt at the end of the string made a nice handle. Finally, choosing a slide that had the star region well centered, I plotted the background stars' locations on the sheet.

The "shooting script" goes as follows: lower the front sheet into place and line up the stellar background on your slide with the position marks on the front sheet. Then pull on the lag bolt to lift the positioning sheet out of the way and project the slide on the main screen. Next, click off two frames of movie film, lower the positioning sheet back into place, change to the next slide, and start over.

This procedure worked well for most of the slides. However, a significant number either were unacceptably bright or contained distracting light sources. The over-bright slides usually had the Moon in the field of view, and such extraneous things as streetlights or porchlights also contributed a measure of glare.

To compensate for the bright slides I needed a background that would dim the skyglow without affecting the light of the stars or planets. After a great deal of experimenting, I came up with the idea of covering the normal white paper projection sheet with one made of black paper covered by black crepe fabric. This dark screen reduced the light level of a projected slide by more than four f/stops. I hung the paper/fabric much as I did the positioning sheet, except that it wasn't hinged and could be attached and removed readily. To keep the black sheet taut and flat, I attached a thin piece of wood, painted black and covered with crepe, to its bottom. Small nails helped to keep it in place.

But the crepe sheet darkened the entire projected image — including, unfortunately, the stars and planets. So to make the stars "pop," I carefully marked the location of about a dozen of them on the background with small dots of White-Out typewriter correction fluid. To take care of the planets — whose positions, of course, changed from frame to frame — the White-Out dots went onto small chips of black paper attached to the crepe by tape loops on the back of them. The final problem, removing unwanted light sources, was easy to fix. I simply placed my hand or a piece of black painted wood a few inches from the projector lens. This threw a soft black shadow that obliterated the offending glare.

Since many viewers would want some orientation, I worked up a titling slide that labels the initial positions of Jupiter, Saturn, and Spica and shows where Mars will make its entrance (it is out of the frame at first). To do this, I projected the first slide of the series on the screen and photographed it with my 35mm still camera on Kodak 2415 negative film, taking great care to keep parallax to an absolute minimum. I developed that frame, mounted it, and projected it as a negative. Taking a black marking pen to the projection screen, I neatly labeled the black dots representing Jupiter, Saturn, and Spica, and included an arrow pointing in the direction Mars would appear from. I then re-shot the screen on 2415, and processing the new picture gave me a labeled positive slide (white stars and labels, black sky) which — finally! — I projected and filmed for a five-second "opener" at the start of the movie.

Anyone interested in undertaking a similar project should bear a few things in mind. First, the original photography may take 9 to 10 months. Second, *each* movie-filming session will take you about 8 to 10 hours — including, of course, all those you bungle due to inexperience. My guess is that anyone starting out probably won't have to do more than three or four sessions before he gets a movie to be happy with. (Don't complain — it took me *nine* tries.) Lastly, the final movie, which I have naturally titled *The Wanderers*, runs about 20 seconds — just about long enough to gobble one handful of popcorn!

Carl Buzzard got started in astronomy in 1969 by taking an astronomy course at Bradley University, where he graduated with a B.S. degree in math. He has made four telescopes, ranging from a 4¼-inch to a 12½-inch. In 1975 he joined the Chicago Astronomical Society and in 1982 was elected president of it. He's now serving his second term as club president.

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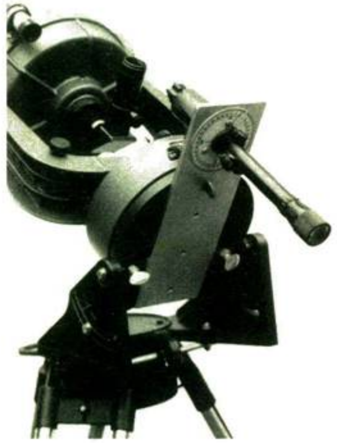

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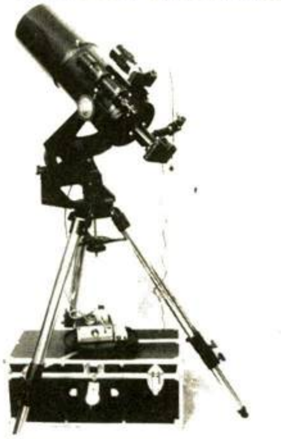

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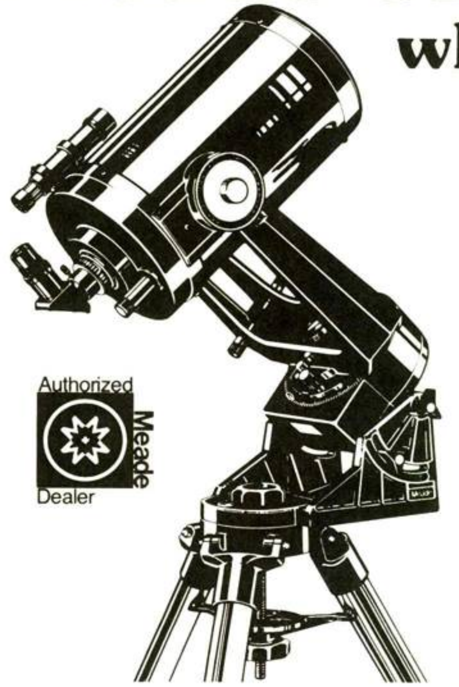

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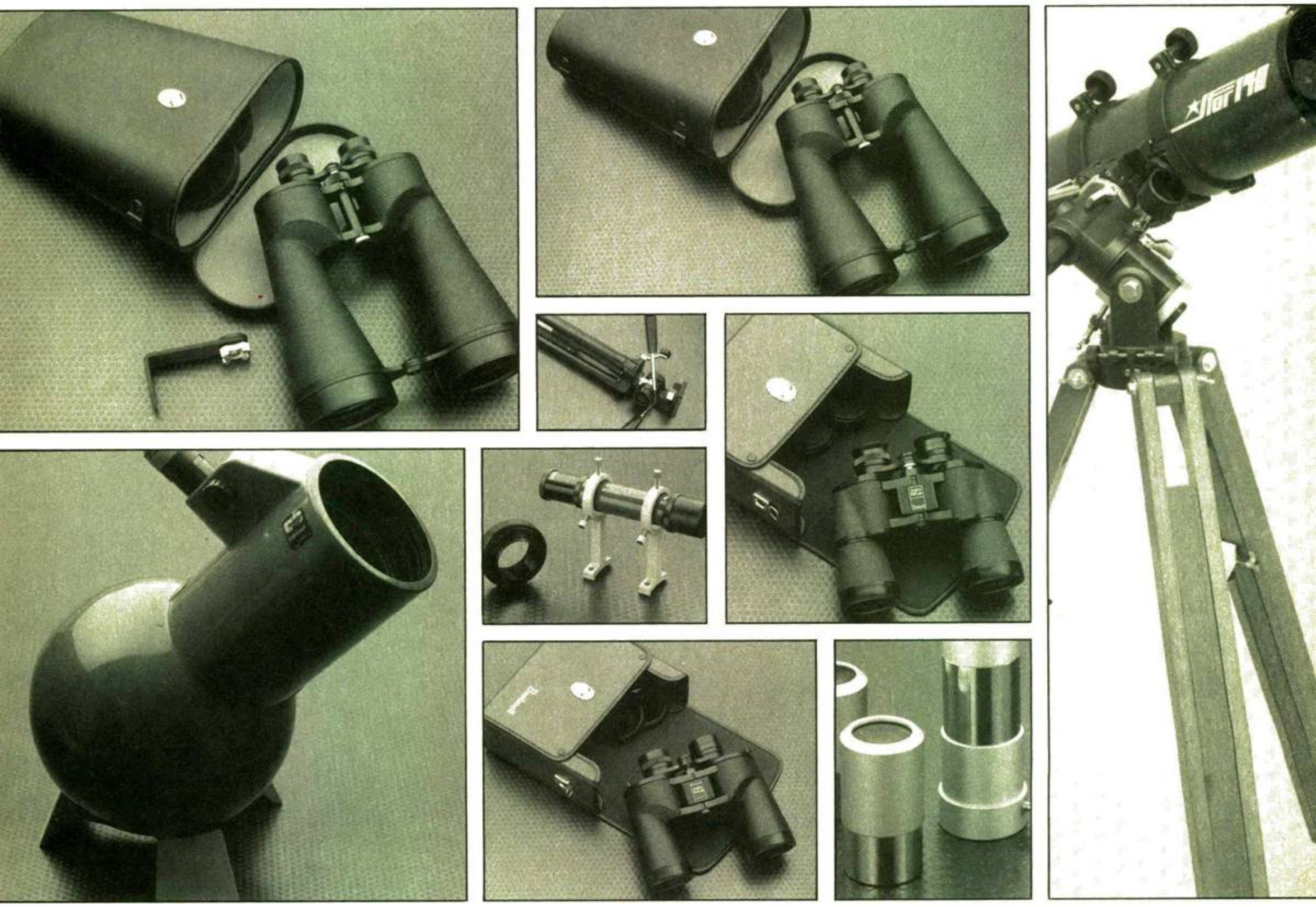

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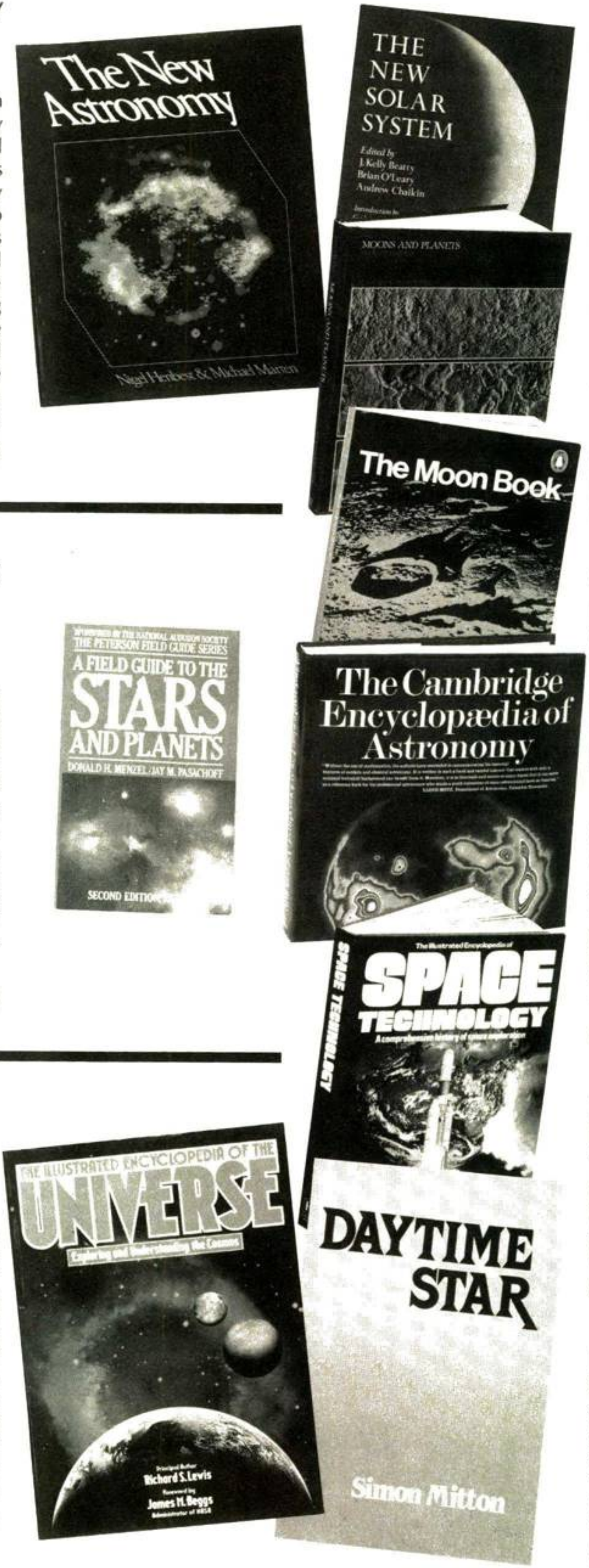
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ASTRONEWS

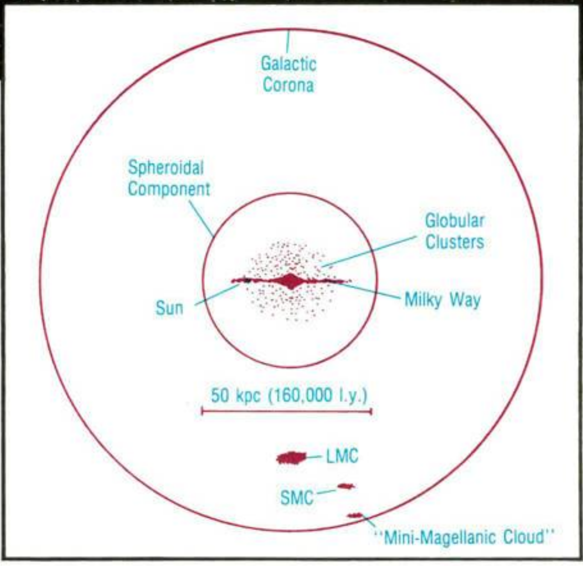
A Third Magellanic Cloud

For hundreds of years observers have been intrigued by the two giant luminous patches of light decorating the southern sky — the Magellanic Clouds. Known to early sailors rounding the Cape of Good Hope, they were first described in detail by the Portuguese navigator Ferdinand Magellan early in the 16th century. More recently, in the early 1920s, astronomers discovered that the two clouds — the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC) — are nearby irregular galaxies that orbit about the Milky Way as satellites and help comprise our Local Group of galaxies along with M-31, M-33, Maffei 1, NGC-6822, and about two dozen others. The LMC lies about 52 kiloparsecs away, measures 8 kpc across, and holds 10^{10} solar masses. Its absolute magnitude is −18.7. The SMC lies 63 kpc off, spans 5 kpc across, and contains 2×10^9 solar masses. It has an absolute magnitude of −16.7.

One of the most enticing research breakthroughs associated with the Magellanic Clouds was the discovery, about 10 years ago, of the so-called Magellanic stream. Australian radio astronomers mapped a long arc of neutral hydrogen extending from the SMC, beyond the south galactic pole, and possibly reaching into the galactic plane. Because the Magellanic Clouds are satellites to the Milky Way, their orbit about us causes them, from time to time, to cut through the plane of our Galaxy. The Magellanic stream is thus probably a loop of gas drawn out of the Milky Way during one of these encounters perhaps half a billion years ago.

Now the same Australian team of radio astronomers has made an even more eventful discovery. Led by Don Mathewson, director of Mount Stromlo Observatory, a group of scientists found that the image representing the SMC is actually made up of two separate galaxies, one behind the other, so that they appear to overlap and look like a single object. "It's all a very complex jigsaw puzzle," said Mathewson. "The Small Magellanic Cloud has puzzled us because there were two galaxies superimposed against one another, just like a double exposure on a photograph. It wasn't until we realized this that what we were seeing made sense. We were then able to prove there were two galaxies being identified singularly as the Small Magellanic Cloud, because each had vastly differing velocities which allowed positive identification."

Terry D. Oswalt



Above: For hundreds of years man has known about two Magellanic Clouds; now there is a third. Right: Schematic diagram showing a 75 kiloparsec radius about the Milky Way, and positions of the clouds.

Early data indicate that the Small Magellanic Cloud indeed may have been a single galaxy but was cut in two by a collision with its larger neighbor about 200 million years ago. Since then the two galaxies — renamed the Mini and the Small Magellanic Cloud Remnant — have been moving apart from each other at a rate of 40 km per second. The Mini now lies 10 kpc behind the Small Cloud. Not much is known about the third Magellanic Cloud, but Mathewson's discovery will surely spark a renewed interest in those wondrous patches of the southern sky.

Second Possible Solar System Found

In mid-December astronomers working frantically to unravel the mass of data sent back by the Infrared Astronomical Satellite (IRAS) happily announced that they had found a second star "orbited by cool, solid material." The star is Fomalhaut, the brightest star in the constellation Piscis Austrinus, a well-known figure of the autumn sky. It lies 22 light-years away and is about 12 times more luminous than the Sun.

Back in August, astronomers on the IRAS science team found the first extrasolar evidence of material orbiting a star when they trained their telescope on Vega for calibration. (See "IRAS and the Infrared Universe," ASTRONOMY, March 1984.) Now that they've discovered a second system, some astronomers on the IRAS team are predicting many such finds in the months of analysis to come.

Does the Universe Rotate?

Possible evidence for the rotation of the universe has developed into a minor controversy. In July, 1982, Paul Birch of the University of Manchester, England, published data as evidence for rotation of the universe. Birch suggested that measurements of the direction of polarization of radio waves from extended radio sources indicated that the universe rotates approximately 10^{-13} radians per year. He argued that the universe shows a high degree of organization, and based this conclusion on the results of polarimetry experiments. These showed an overall shift in one direction for the northern sky and a general shift in the opposite direction for the southern sky. Birch could not explain this apparent "twist" by assuming intra- or extra-galactic magnetic field disturbances or errors in the calibration of his instruments.

However, Sterl Phinney and Rachel Webster of the Institute for Astronomy in Cambridge, England, do not agree. They used computer simulations of Birch's data to determine the statistical significance of his results. They could find no evidence of a twist between the alignment of an extended radio source in Birch's sample and its position in the sky.

Phinney and Webster also indicated that the source-averaged data of Birch "does not have any simple physical interpretation,"

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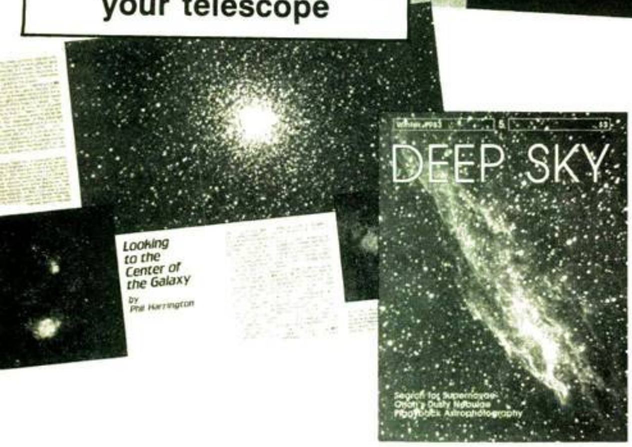

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possibly due to systematic errors in correcting for the effect of the local interstellar medium. Phinney and Webster concluded that Birch's data do not justify the conclusion of universal rotation.

Birch remains unconvinced. In a rebuttal, he argued that Phinney and Webster misinterpreted his data. He added that while incorporation of a correction factor for the local interstellar medium deserves attention, it does not change the level of significance of his final result.

One important consequence of the rotation of the universe is the possible violation of Ernst Mach's principle, previously the only justification for a non-rotating universe. Expressed simply, this principle states that all forces of Earth are countered by equal but opposite forces in the universe — possibly caused by an even distribution of matter throughout the universe. The results of Paul Birch and his team suggest that the universe has an uneven distribution of matter. This could possibly change how we measure the interrelationships of gravity, mass, and density.

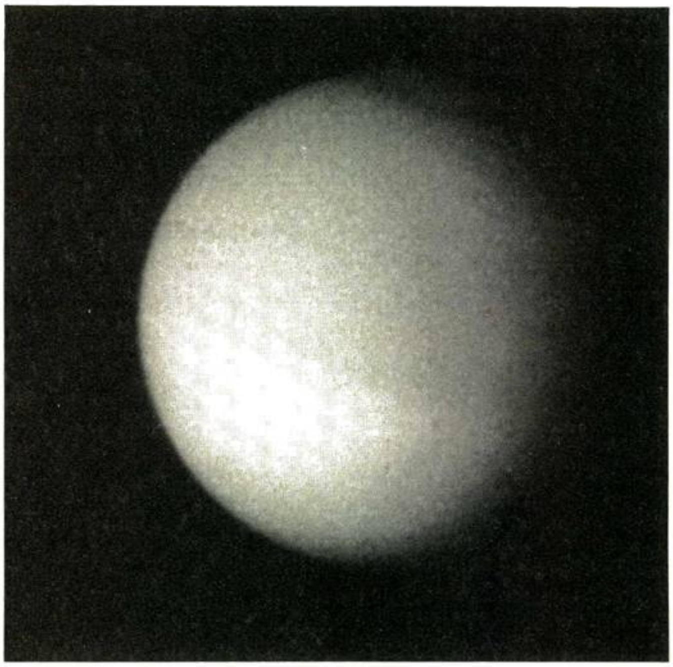
On the theoretical side, John Ellis and Keith Olive of the European Center for Nuclear Research in Geneva have extended the inflationary model of the Big Bang to include the effects of spin in the early universe. Observations of the uniform microwave background radiation indicate that the universe as a whole can rotate no faster than one revolution every 10^{17} years. Why so slowly? According to the inflationary universe model, the cosmos underwent a brief period of incredible expansion shortly after the Big Bang (see "The Decay of the False Vacuum," ASTRONOMY, November 1983). If the universe had any spin to begin with, it would be greatly reduced during the expansion to conserve angular momentum — just as an ice skater's spin decreases when the arms are extended. Ellis and Olive comment that this new model of the Big Bang makes Mach's principle redundant — the universe now rotates very slowly today because its size increased so much shortly after its birth. *Alfred M. Sciuto.*

Tunguska Revisited: Ice or Rock?

Seventy-six years ago this June 30, a brilliant fireball streaked across the morning sky of central Siberia. The object exploded about 8.5 kilometers above a sparsely populated region near the Stony Tunguska river, scorching, stripping, and flattening thousands of trees directly below it. Seismographs in Europe recorded the blast, and its shock wave twice circled the globe. In the popular press, ideas about the origin of the explosion have ranged from the crash of a nuclear-powered spaceship to a collision with a miniature black hole. In the scientific literature, however, one explanation has endured for the last 50 years — that the head of a small comet collided with Earth. Recently, Zdenek Sekanina, an astrophysicist at the Jet Propulsion Laboratory, challenged that notion.

While the comet hypothesis has been around since 1930, Czechoslovakian astronomer Lubor Kresak came to a more specific conclusion in 1978. Kresak noted that the Siberian event occurred near the peak of the Beta Taurid meteor shower, a stream of cometary debris associated with Encke's Comet, and suggested that Tunguska was just a small, inactive piece of that comet. But according to Sekanina, "existing information on the fall rules out the possibility that the object was a comet fragment, active or extinct." The Tunguska object apparently did not undergo any major breakup until the final explosion — an almost instantaneous dissipation of about one million tons of matter. Earth's atmosphere doesn't decelerate such a massive object very efficiently, so before exploding, any comet fragment would have been moving at the typical velocity of a comet in space — on the order of 30 kilometers per second. Comets are thought to be made up of dust and various ices; could cometary material, known for its extreme fragility, survive enormous aerodynamic pressures long enough to penetrate into the lower atmosphere? "It is inconceivable," Sekanina remarks. At 8.5 kilometers, the height at which the object broke up, resistance from the atmosphere exceeded by 1,000 times that which destroys cometary particles burning up during meteor showers. In addition, Sekanina argues that, based on the object's precollision orbit, any association with Comet Encke is unjustified.

What, then, did explode in the sky that June morning? Sekanina, writing in the September 1983 *Astronomical Journal*, concludes that the object most consistent with the accumulated observations is a small Apollo-type asteroid, between 90 and 190 meters across, traveling at about 10 kilometers per second. Before striking Earth, it probably orbited the Sun at a distance of 1 to 1.5 astronomical units.



NASA

According to a hypothesis put forth by Caltech astronomers in December, Titan is enshrouded in a kilometer deep ocean of ethane and acetylene mud, and enveloped in a hazy nitrogen atmosphere.

Titan's Ethane Ocean

Three Caltech astronomers published a startling hypothesis on the composition of Saturn's moon Titan in the December 16 issue of *Science*. Scientists David J. Stevenson, Yuk L. Yung, and graduate student Jonathan I. Lunine described Titan as a strange world covered by a "kilometer-deep, muddy-brown ocean of ethane, with a bottom of acetylene mud, and fed by a continual mist of ethane rain and acetylene snow through a hazy nitrogen atmosphere."

This new idea explains some puzzling results from Voyager 1's study of Titan. As the spacecraft flew by Titan in 1980, it detected a nitrogen-rich atmosphere also containing significant amounts of methane. But experiments, such as the one that measured the bending of radio waves as Voyager passed behind the moon, revealed that Titan's temperature profile — its temperature change with respect to height above its surface — resembled a desert-like planet. It also showed that the amount of methane in Titan's lower atmosphere, about 3%, is insufficient for a methane ocean, given Titan's surface conditions.

Many planetary scientists used the Voyager results to paint a picture of Titan as a dry, desolate world. But others questioned that assumption, pointing out that ultraviolet radiation would be constantly tearing apart methane molecules in Titan's upper atmosphere, releasing hydrogen into space. This meant that Titan's atmosphere would have to be continually resupplied with methane.

The new hypothesis put forth by the Caltech astronomers explains this problem. According to Stevenson, Yung, and Lunine, Titan once did have a methane ocean, but as the methane steadily evaporated, it reacted with sunlight in the upper atmosphere and produced ethane and acetylene, which condensed out. At Titan's temperature of −180° C, the ethane is a liquid and the acetylene a solid, which settles to the bottom of the ocean.

Over the last 4.6 billion years, this process on Titan has slowly converted the titanian ocean into a mixture of 70 percent ethane, 25 percent methane, and 5 percent nitrogen. According to the Caltech astronomers' calculations, the ocean is about one kilometer deep, and the acetylene sludge layer at its bottom is about 100 to 200 meters thick. Because ethane's vapor pressure is lower, the surface has a "dry" appearance suggested by the Voyager radio experiment.

"A kilometer-deep ocean would probably cover most topography that could be expected from meteorite impacts," said Lunine. "A few islands of water ice — the 'bedrock' of Titan — might poke up. Impurities

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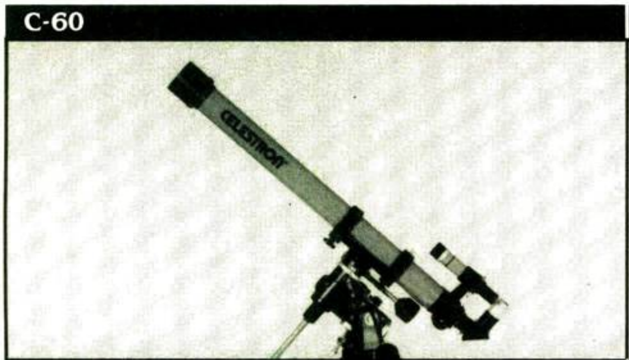

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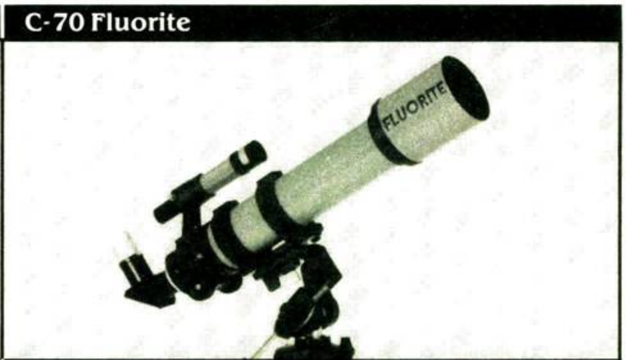

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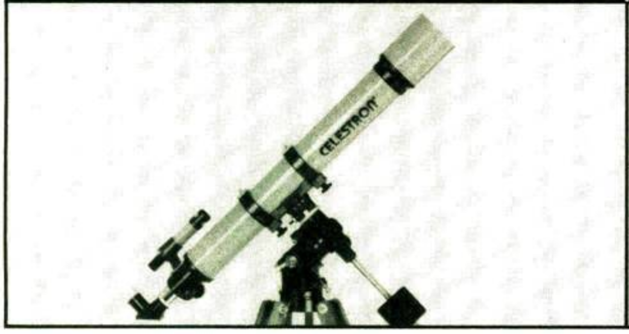

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ASTRO NEWS

of heavy hydrocarbons would probably make the ocean a mucky red color, matching the cloudy and hazy red of the sky. Organic solids and tars would probably coat the ocean bottom and even island surfaces."

"It is possible, however, that the ocean bottom is not simply a placid repository of hydrocarbon garbage," he said. "Titan's interior might still hold a liquid magma of ammonia-water, which occasionally could find its way to the surface. Such a mixture, erupting at a temperature of −100° C into the −180° C ocean would be no less dramatic than basaltic lava at 1300° C erupting into our 10° C terrestrial oceans."

Space Telescope Gets Name

The Space Telescope, NASA's orbiting astronomical observatory scheduled for launch in 1986, has been renamed to honor one of this century's most influential and notable astronomers. Now known as the Edwin P. Hubble Space Telescope, the craft holds a 2.4-meter mirror and is expected to make revolutionary discoveries in galactic and extragalactic astronomy. It will look seven times farther than any ground-based instruments, offer 10 to 20 times better resolution than any Earth-based telescope, and penetrate down to stellar magnitude 27.

A native of Missouri, Hubble received a degree in astronomy from the University of Chicago in 1910 and won a Rhodes Scholarship to study law at Oxford. In an on-again, off-again fashion, Hubble practiced law and served in the Army before returning to astronomy full time as a staff member at the Mount Wilson Observatory. Working with the 100-inch telescope at Mount Wilson, Hubble made perhaps the most startling and fundamental discovery of this century in astronomy — that galaxies are separate large bodies of stars and are distinct from the smaller gas clouds in our Milky Way. Later in his career Hubble discovered that the universe is expanding; the coefficient relating a galaxy's distance and velocity is known as the Hubble constant. After leading one of the most productive and important careers in modern astronomy, Hubble died in 1953.

ASTRO CALENDAR

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April 20-22	**Third Annual Conference on Space Development,** San Francisco, California. Sponsored by the L-5 Society. Contact: Charles Curley, Third Annual Conference on Space Development, 1275 Fourth St. #242, Santa Rosa, CA 95404. Phone (707) 538-1227.
April 28	**Dedication of 3-meter Radio Telescope.** Custer Institute, Southold, Long Island, New York. Workshops on amateur radio astronomy and star party. Contact: Tom Carey, Vanderbilt Planetarium, Centerport, NY 11721.
May 5	**Astronomy Day.** For more information, contact: Gary Tomlinson, Astronomy Day Coordinator, Astronomical League, Chaffee Planetarium, 54 Jefferson S.E., Grand Rapids, MI 49503. Phone (616) 456-3985. The Astronomical Association of Northern California hosts Astronomy Day on April 7.
May 25-28	**Riverside Telescope Maker's Conference,** Big Bear, California. Contact: Cliff Holmes, 8642 Wells Ave., Riverside, CA 92505.
May 30-June 3	**Texas Star Party,** Fort Davis, Texas. Contact: TSP '84, Dept. A, 128 N. Commerce, Burleson, TX 76028.
June 30	**Northeast Regional Astronomical League Convention,** Sperry Observatory, Cranford, New Jersey. Sponsored by Amateur Astronomers, Inc. Contact: Roger Tuthill, (800) 223-1063 (toll-free).
July 7-12	**Joint Meeting of the Astronomical Society of the Pacific and the Western Amateur Astronomers,** University of California, Santa Cruz, California. Contact: Summer Meeting, A.S.P., 1290 24th Ave., San Francisco, CA 94122.
July 10-14	**Case for Mars II,** Boulder, Colorado. A workshop on the future of manned missions to Mars, sponsored by the Mars Institute of the Planetary Society, the Boulder Center for Science and Policy, and the University of Colorado Space Interest Group. Contact: Case for Mars, P.O. Box 4877, Boulder, CO 80306.
July 12-14	**Microcomputers in Astronomy II.** Fifth annual IAPPP-Fairborn Symposium, Fairborn, Ohio. Contact Russell M. Genet, Fairborn Observatory, 1247 Folk Rd., Fairborn, OH 45324.
July 28	**Stellafane,** Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Rd., Sudbury, MA 01776.
August 1-4	**ALCON '84,** National Convention of the Astronomical League. Carroll College, Waukesha, Wisconsin. Hosted by Milwaukee Astronomical Society. Contact: ALCON '84, P.O. Box 275, Mequon, WI 53092.
August 1-4	**Astromart '84,** an astronomy equipment fair held simultaneously with ALCON '84. Carroll College, Waukesha, Wisconsin. Hosted by ASTRONOMY Magazine. Contact: Dana-Lynne Terry, Advertising Coordinator, ASTRONOMY Magazine, P.O. Box 92788, Milwaukee, WI 53202. Phone (414) 276-2689.

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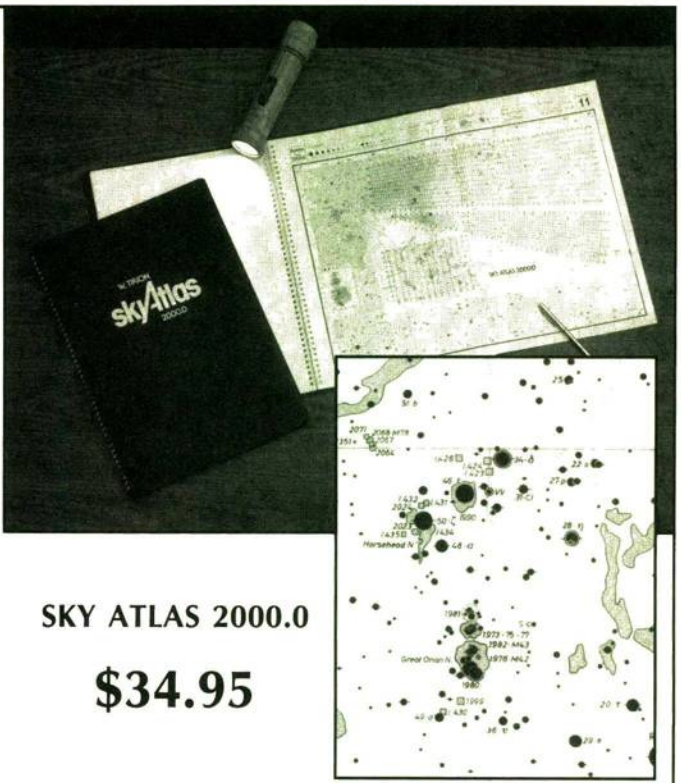

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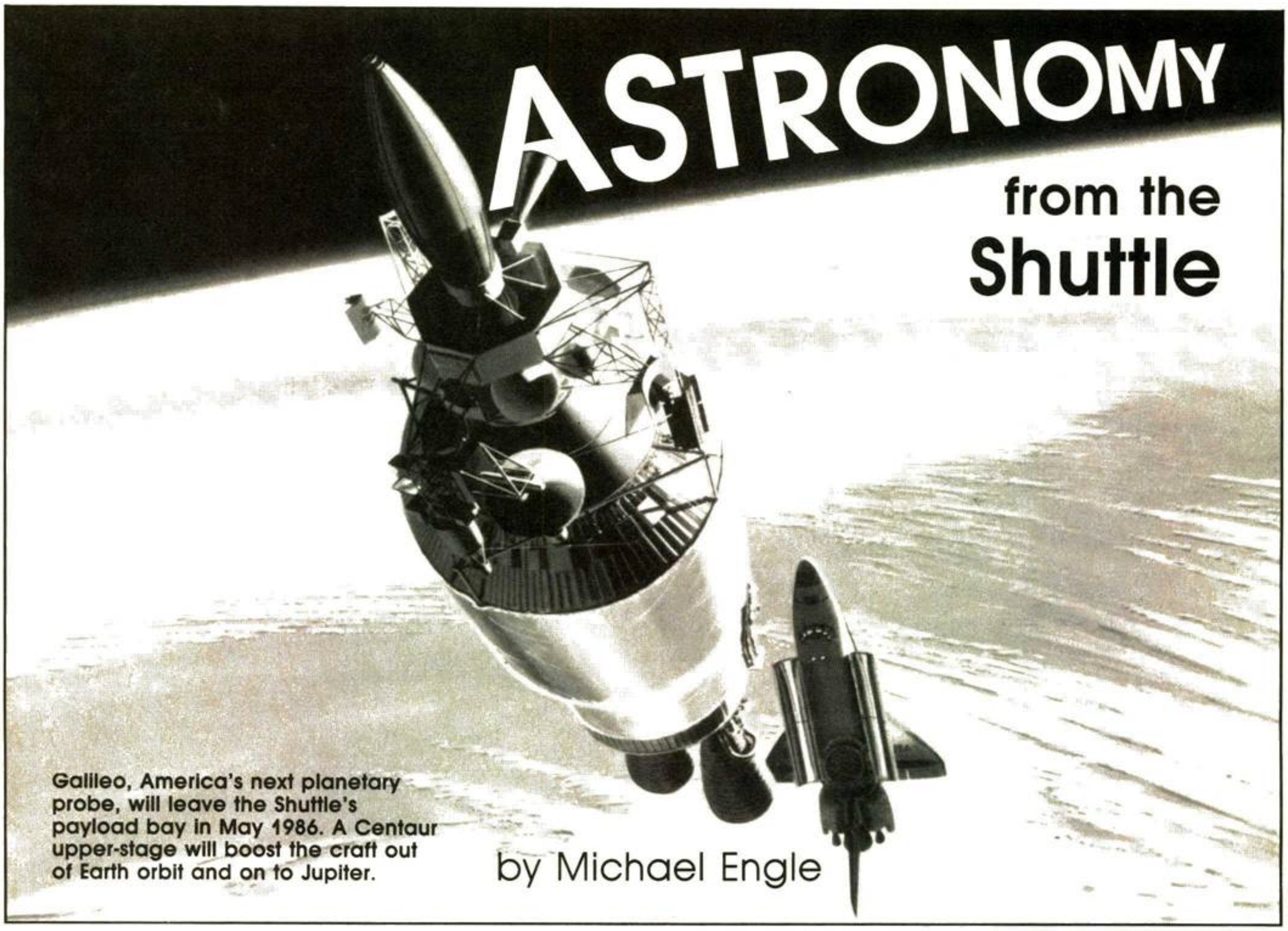
ASTRONOMY from the Shuttle



Galileo, America's next planetary probe, will leave the Shuttle's payload bay in May 1986. A Centaur upper-stage will boost the craft out of Earth orbit and on to Jupiter.

NASA art

by Michael Engle

Three hundred and twenty miles above Earth, the Space Shuttle Atlantis points its payload bay toward deep space. Minutes later, its precious cargo slowly emerges, spreads wing-like solar panels, opens a door on the end of its cylindrical body, and begins its mission — one that promises to revolutionize the ancient science of astronomy. The cargo is the Space Telescope, and it will allow astronomers to view the universe as never before. It will see seven times farther, view objects 50 times fainter, and have 10 times the resolution of the most powerful ground-based telescope. It also marks the beginning of a new era in astronomy — the age of the Space Shuttle.

The dictionary defines astronomy as "the scientific study of the universe beyond the Earth." For centuries, astronomers plagued by the adverse effects of Earth's atmosphere have longed to conduct their science in its true element — "the universe beyond the Earth" or, more familiarly, space. Earth's atmosphere effectively blocks out all electromagnetic radiation beyond the near-ultraviolet (2,900 Angstroms) and the near-infrared (12,000 Angstroms). By placing their instruments in space, astronomers will gain access to the entire electromagnetic spectrum, instead of the narrow "window" available on Earth.

In the 20th century, the use of rockets opened the way for astronomers to realize their long-held dream of research in space. Early studies with sounding rockets led to more sophisticated projects — the Orbiting Solar Observatory (OSO), the Orbiting Astronomical Observatory (OAO), the High-Energy Astronomy Observatory (HEAO), and the Infrared Astronomical Satellite (IRAS). These projects were enormously fruitful, revealing such objects as evolving protostars, huge ultraviolet hydrogen clouds around comets, and over 200 X-ray sources. Obviously, space-based instruments are invaluable to modern astronomy. Equally valuable were the planetary probes, such as Mariner, Pioneer, Viking, and Voyager. Their findings have given us all a greater appreciation of the beauty and mystery of our own solar system. But the National Space Transportation System, better known as the Space Shuttle, will revolutionize space-based astronomy. Already, almost 20 astronomy payloads are scheduled to fly on the Shuttle, and many more are planned.

SPARTAN

The first Shuttle-launched astronomy payload will be the Shuttle Pointed Autonomous Research Tool for Astronomy, wisely abbreviated to SPARTAN. It will fly aboard the Shuttle several times, beginning this August on STS-16. SPARTAN was developed from existing sounding-rocket technology and is nothing more than a large box containing experiments and their related electronics. The Shuttle's robot arm will lift it out of the payload bay and release it alongside the spacecraft. As indicated in its name, SPARTAN depends on the Shuttle to point it in the right direction. Once SPARTAN completes its observations, the Shuttle's arm will capture it and place it back in the payload bay, where it will be stored for return to Earth. After landfall, SPARTAN will be refitted with new experiments, to be flown again as many times as desired.

SPARTAN-1 will carry an array of proportional X-ray counters to detect and study very high-energy astronomical objects. SPARTAN-2, scheduled for flight on STS-31 in November 1986, will carry two coronagraphs for monitoring the Sun's corona, an ultraviolet telescope, and a charge-coupled device (CCD) sensitive to visible light. SPARTAN-3 will fly on STS-54 in May 1987 and will be an ultraviolet astronomy payload. Future SPARTANs will study high-energy astrophysics, solar physics, stellar astronomy, and plasma physics.

Astro

Astro is another reusable package of experiments. In March of 1986, the first of three Astro payloads will be launched aboard STS-35. The package is an ultraviolet astronomy payload mounted on a pallet outside the European Space Agency's Spacelab, along with an "igloo," a pressurized cylinder that shelters sensitive electronic equipment. The pallet is a U-shaped aluminum frame 4 meters wide by 3 meters long. The Shuttle's payload bay can carry up to five pallets at a time. Experiments are attached to removable racks, which are then slid into place on the pallets. The Astro equipment will include an instrument pointing system, used to point the equipment in the right direction, a star tracker that locates bright stars for positional reference, and a radiator for cooling the equipment.

Astro-1's objective is to conduct ultraviolet surveys of Halley's Comet. Launched to coincide with the comet's maximum brightness, Astro-1 will scrutinize Halley with an ultraviolet imaging telescope (which has 1.8 arcsecond resolution), a far ultraviolet telescope/spectrometer, and an ultraviolet photoelectric polarimeter for studying the polarization of light from the comet. Future Astro payloads will concentrate on other areas of astronomical interest, depending on funding.

ISPM

One of the most ambitious Shuttle projects is the International Solar Polar Mission (ISPM), the first probe to study the polar regions of the Sun. Slated for STS-37 in May of 1986, a Centaur upper stage will boost the craft into a trajectory toward Jupiter. Jupiter's immense gravitational field will deflect the probe out of the ecliptic, into an orbit inclined nearly 90 degrees to the plane in which the planets orbit the Sun. The craft will then head back in toward the Sun and pass over its polar regions.

Although ISPM was originally conceived as a two-spacecraft joint venture between the U.S. and Europe, NASA was forced to cancel its probe due to budgetary problems. The loss of one probe will degrade results somewhat, but astronomers should still be able to accomplish their primary objective — studying the Sun's structure and emissions as a function of latitude from equator to poles. Scientists hope to explore mechanisms relating solar activity to terrestrial weather and climate. A secondary objective is to study interplanetary physics and the jovian magnetosphere during the Earth-to-Jupiter phase of the flight.

Galileo

America's next planetary probe, Galileo, will fly aboard STS-38 in May 1986. NASA established Galileo — originally known as the Jupiter Orbiter and Probe mission — as its top priority planetary mission in 1975. Galileo's development has been turbulent, mostly because of changes in propulsion systems. Now firmly committed to the Centaur upper stage propulsion system, scientists are gearing up for an intensive and detailed study of the Jupiter system with Galileo.

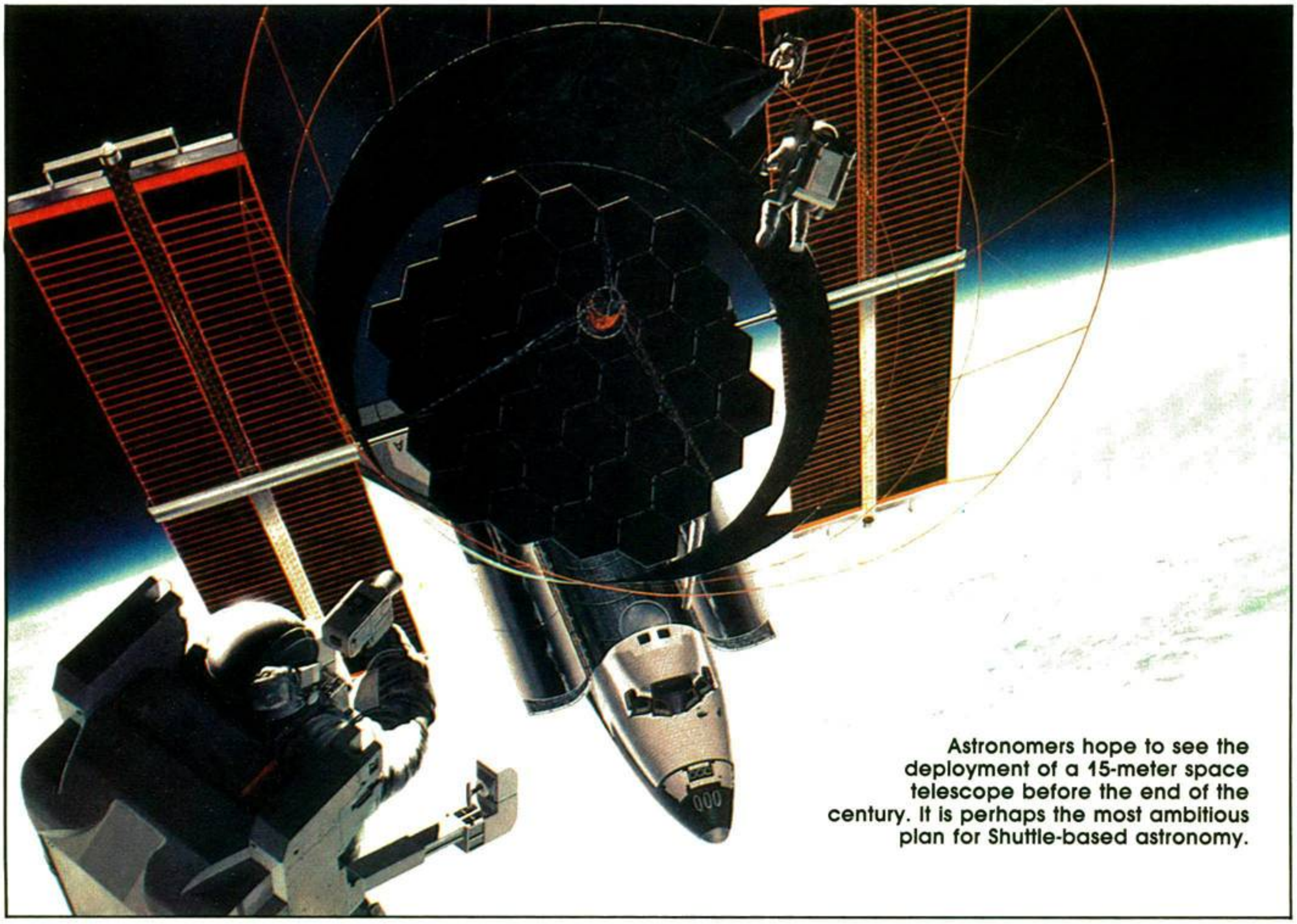
Galileo consists of two spacecraft, an orbiter and an atmospheric probe. The probe will enter Jupiter's atmosphere and relay data to Earth via the orbiter. Within an hour, the probe will plunge over 100 km below the cloud tops, where high temperatures and an increasingly radio-opaque atmosphere will end its operational life. The orbiter will continue to relay data on Jupiter's fields and particles, while simultaneously surveying its satellites. The ability to conduct both operations with the same spacecraft is a major advance in spacecraft technology.

Serious planetary exploration demands the study of both the surface of a planet and its associated fields (gravitational, magnetic, and electric) and particles. This poses a dilemma: remote sensing of a surface requires a stable, fixed platform, while field and particle surveys are best conducted from a rotating platform. NASA resolved this incompatibility by making Galileo a "dual-spinner," with one section rotating and the other non-rotating — again eliminating the need for two separate spacecraft.

Galileo promises to be the most productive planetary probe ever launched. But without the heavy lift capability of the Space Shuttle, Galileo's promise could not be fulfilled. (See "Gallileo, Mission to Jupiter," ASTRONOMY, February 1982.)

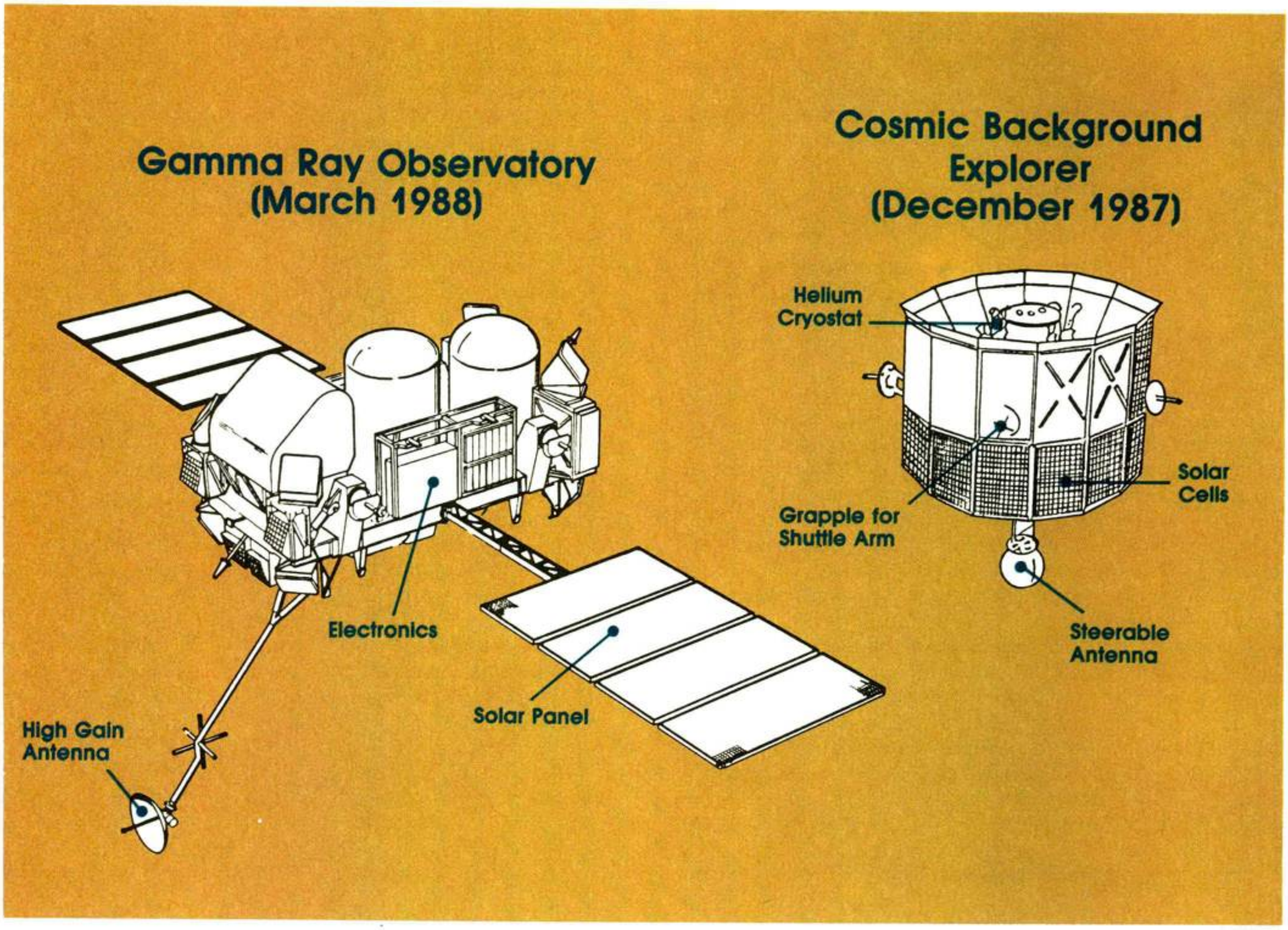
The Space Telescope

As early as 1923, the German rocket scientist Hermann Oberth proposed placing a telescope in Earth orbit, where atmospheric turbulence and absorption would not be a problem. Over six decades later, in August of 1986, the Space Shuttle Atlantis will loft the Space Telescope into Earth orbit. The Space



Astronomers hope to see the deployment of a 15-meter space telescope before the end of the century. It is perhaps the most ambitious plan for Shuttle-based astronomy.

NASA art by Paul Hudson



Telescope promises to do nothing less than revolutionize optical astronomy. Its goals: to provide at least 0.1 arcsecond resolution over a ten-hour period, observe stellar magnitudes as faint as 27, perform surface-brightness photometry, and maintain operations for at least 15 years. To accomplish these objectives, the satellite must be able to point the correct scientific instruments at the desired astronomical object and make sure that stray light from the Sun, Earth, and Moon does not exceed a visual magnitude of 23. Shuttle astronauts, carrying out maintenance, repair, and instrument replacement, will insure the healthy operation of the Space Telescope. Indeed, the instrument will even be returned to Earth via the Shuttle every five years for major refurbishments.

The major components of the Space Telescope are its 2.4-meter diffraction-limited optical telescope, the support systems module, and six scientific instruments. Four of the instruments — the faint object camera, the faint object spectrograph, the high-resolution spectrograph, and the high-speed photometer — are located on the instrument's long axis. The wide field/planetary camera is located along the radial axis. All these instruments use light gathered by the Ritchey-Chretien Cassegrain optical system, which produces excellent images over a wide field of view.

The faint object camera, developed by the European Space Agency, is designed to view the faintest limiting magnitudes with the highest angular resolution possible. The FOC actually consists of two independent camera systems, one working at f/96 and the other at f/48. Together, they will be used to study such objects as RR Lyrae stars, Cepheid variables, globular clusters, and giant regions of ionized hydrogen gas. The camera will also observe condensing gas clouds, shock fronts, and search for evidence that quasars and BL Lacertae objects are the bright nuclei of faint galaxies.

The faint object spectrograph will perform spectroscopy on both faint and bright objects at ultraviolet and visible wavelengths. Its applications include: high-resolution spectra of quasars, Seyfert galaxies, and other active galactic objects, observations of planetary nebulae, measurement of the radial velocities of globular clusters, spectrometry of comets, and spectropolarimetry of quasars, white dwarfs, and neutron stars.

The high-resolution spectrograph is an ultraviolet instrument that uses high-resolution photon detectors to measure light intensity, performing spectroscopy at wavelengths from 1100 to 3200 Angstroms. The spectrograph will be used to observe the interstellar medium, nearby gas clouds, and the atmospheres and auroral activity on other planets and satellites.

The high-speed photometer will provide accurate photometric studies over a broad wavelength range. It will make several interesting observations, among them searches for optical views of radio pulsars, accurate measurements of stellar diameters, and physical profiling of the planets.

The wide field/planetary camera will be used for both wide-field/deep-sky surveys and high-resolution observations of faint objects. This instrument will also be useful in studying distant galaxies, motions in supernova remnants, and planetary atmospheres.

The telescope's fine guidance system, three sensors surrounding the optical axis of the ST, points it with extreme accuracy. Since this guidance system can also be used for precise astrometric measurement, it qualifies as a sixth instrument.

To quote NASA, "The Space Telescope's potential is so great that not only the astronomers, but most members of the scientific community see it as a herald of a new era, an era of superdiscoveries, of conscious expectation of the unexpected."

ROSAT

In September 1987, STS-61 will carry the Roentgen satellite, or ROSAT, to its operational orbit around the Earth. The two-fold objective of the ROSAT observatory is (1) to conduct a six-month-long, all-sky survey of X-ray sources, and (2) to perform a year-long, detailed study of selected individual X-ray sources.

ROSAT is a German payload controlled from a ground-based, German payload operations control center.

COBE

Cosmology is the study of the origin and evolution of the universe. Cosmologists today agree that the universe was probably formed by a cataclysmic explosion about 20 billion years ago, nicknamed the "Big Bang." Four pieces of evidence support the Big Bang theory — the distribution of matter in the universe, the abundances of hydrogen and helium, the extremely fast, outward recession of distant galaxies, and the cosmic background radiation. Although the last of these is the most difficult to measure because of atmospheric disturbance, its study is essential in refining our knowledge of the Big Bang.

Lifting off from Vandenburg Air Force Base, California, in December 1987, the Space Shuttle Discovery will deliver the Cosmic Background Explorer (COBE) into an orbit that passes over both the north and south poles of Earth, high above any atmospheric disturbance. COBE will explore the diffuse background radiation of the universe between the wavelengths of one micrometer and 12 millimeters.

Once deployed from the Shuttle, COBE's own propulsion system will boost it to a high orbit synchronous with the Sun — this means that the satellite will maintain the same position in relation to the Sun. COBE's orbit ensures that it always passes over the terminator (the line defining sunrise and sunset), so neither the Earth nor the Sun will interfere with its instruments. Because of its orbit, COBE will be able to survey the entire sky twice during its one-year lifetime, with 10 to 100 times the accuracy of ground-based instruments. Full sky coverage will also allow COBE to compensate for interstellar and interplanetary dust and determine if the intensity of the background radiation changes in different parts of the sky.

COBE will carry three astronomical instruments aboard its three-axis stabilized, rotating platform. Its far-infrared spectrometer will measure the spectrum of the 3° Kelvin background radiation in the 0.1 to 10 millimeter wavelength range. Its differential microwave radiometer will measure background radiation at wavelengths of 3.3, 5.7, 10, and 13 millimeters. The third instrument, the diffuse infrared background experiment, will measure the angular distribution of diffuse infrared background radiation to a sensitivity of 10^{-13} watts per square centimeter.

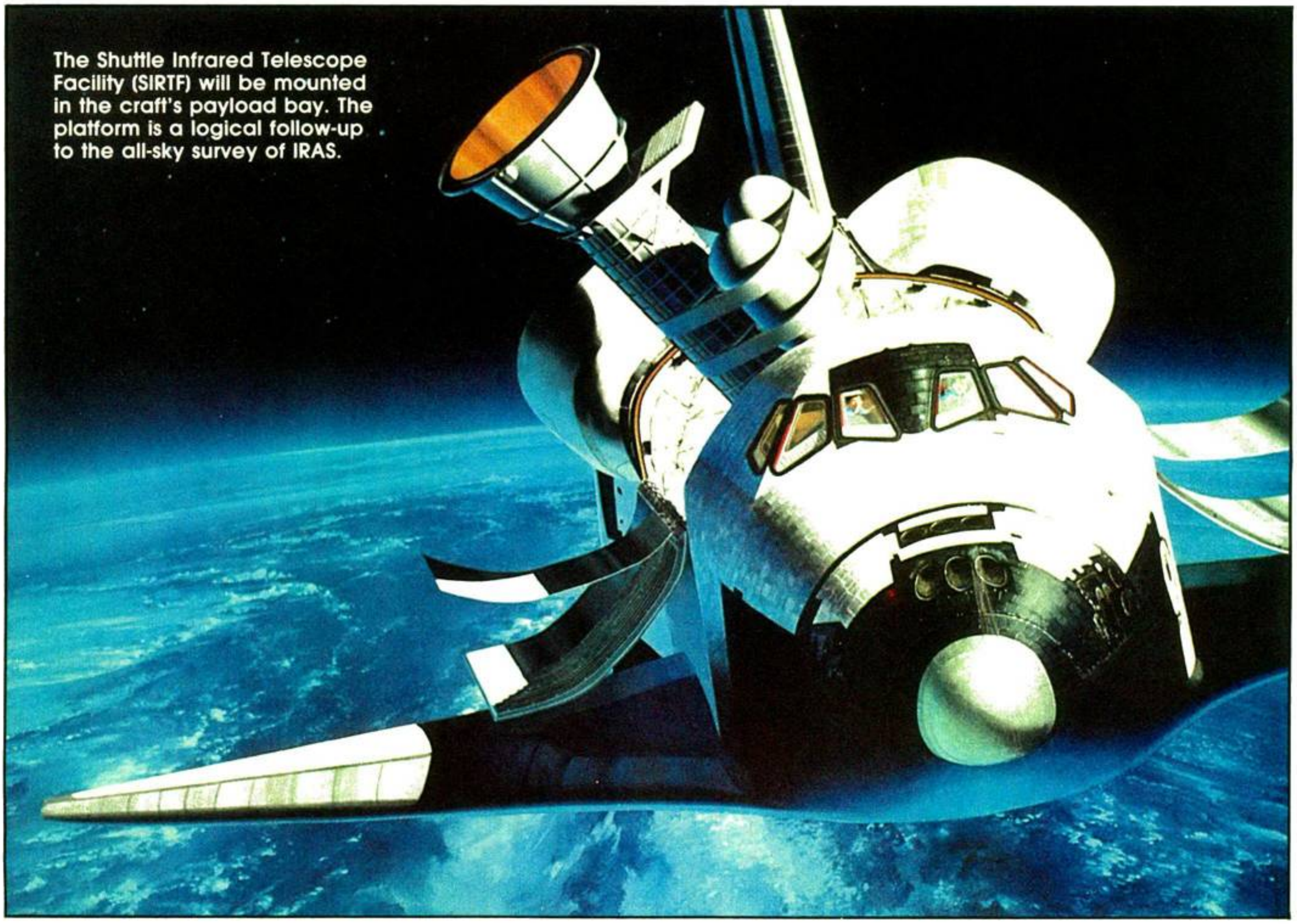
With its array of scientific instruments, COBE should be able not only to measure the spectrum and angular distribution of the background radiation left over from the Big Bang, but also to detect radiation from primordial stars and galaxies. From its vantage point in space, COBE will dramatically increase our knowledge of the early universe.

GRO

The study of gamma rays provides more information about high-energy processes and objects than any other field of astronomy. Gamma rays provide the most direct measure of such phenomena as synthesis of elements within stars, galactic dynamics, and discrete sources such as black holes, quasars, and supernovae. Gamma rays, however, are completely blocked out by our atmosphere, so astronomers are forced to conduct high-energy observations from high-altitude balloons or spacecraft. Unfortunately, balloon flights don't last very long, and previous spacecraft were limited in the size of the instruments they could carry. But the heavy-lift capability of the Space Shuttle opens the opportunity to fly much heavier spacecraft, and one of these is the Gamma Ray Observatory (GRO), to be launched aboard STS-71 in March 1988.

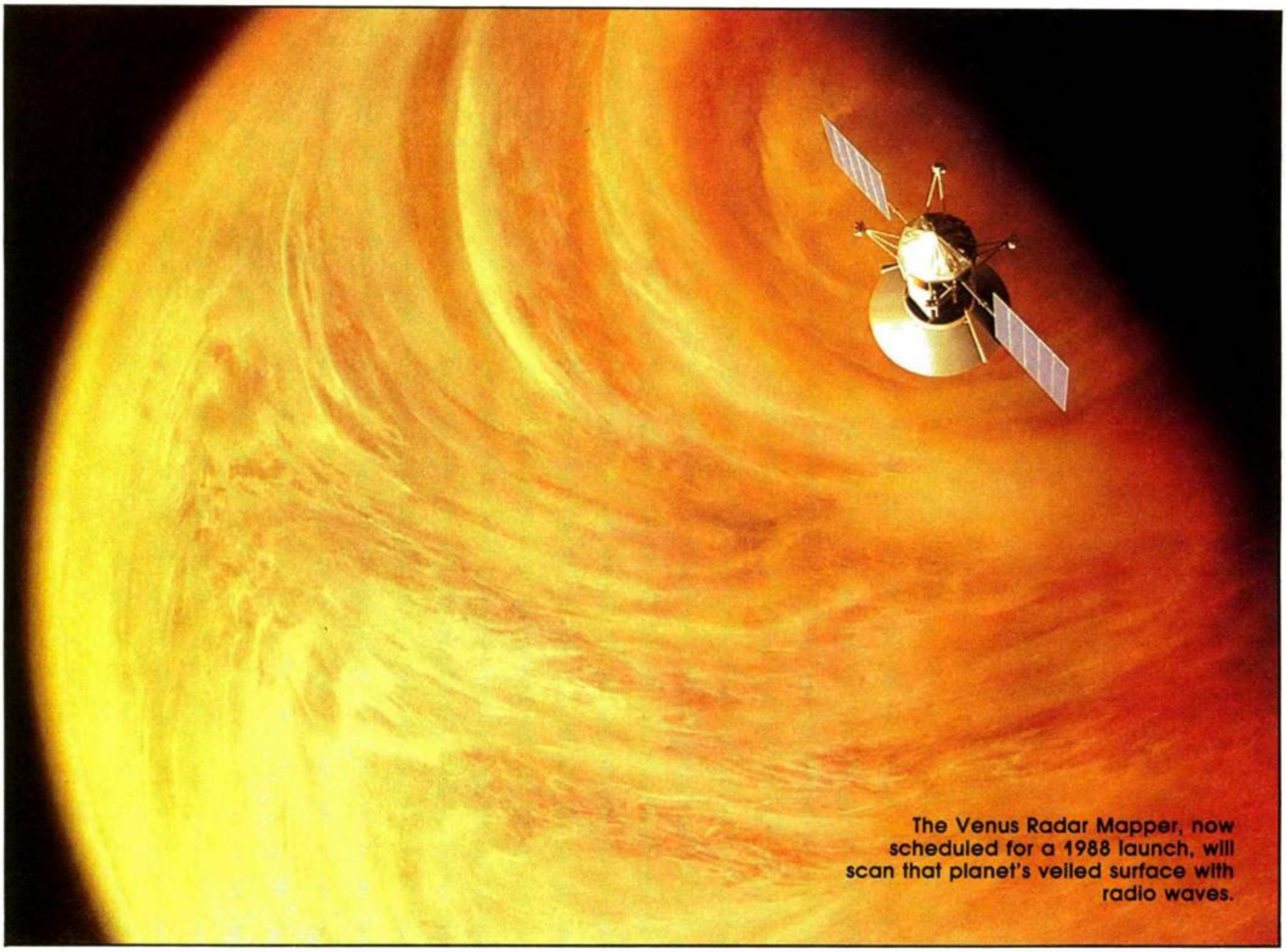
The observatory will provide a full-sky gamma-ray survey. A large payload — 24 feet long and weighing 31,000 pounds — it is designed for a two-year mission, during which Shuttle astronauts will visit it and make any necessary repairs. At the end of its operational mission, it may be retrieved by the Shuttle.

GRO will use four instruments to accomplish its survey: an oriented spectrometer, two high-energy telescopes, and an



The Shuttle Infrared Telescope Facility (SIRTF) will be mounted in the craft's payload bay. The platform is a logical follow-up to the all-sky survey of IRAS.

NASA art by Paul Hudson



The Venus Radar Mapper, now scheduled for a 1988 launch, will scan that planet's veiled surface with radio waves.

NASA art by Paul Hudson

experiment for detecting bursts and transient sources. Combined, these instruments will study the dynamic forces at work in neutron stars and black holes, explore our Galaxy and others in the gamma-ray range, study gamma-ray emitting objects whose nature is not understood, and search for the evaporation of primordial black holes. From such studies, GRO will reveal our universe in a new light, one that has been hidden from us for too long.

VRM

The Venus Radar Mapper (VRM) was conceived to replace the Venus Orbiting Imaging Radar, which was canceled because of its high cost. Set to fly on STS-72 in April 1988, VRM will use a synthetic-aperture radar and a radar altimeter to conduct an extensive survey of the cloud-shrouded planet Venus. Venus is important to astronomers because of its similarity to Earth. VRM should help to answer questions about venerian geological and atmospheric processes, history and relationship to the Earth.

The project is part of a new generation of spacecraft — relatively low in cost, with extensive use of "off-the-shelf" components. After VRM is deployed from the Shuttle, a Centaur upper stage will boost it toward Venus. Before deployment, VRM will be thoroughly checked out by the Shuttle's crew and returned to Earth if any problems arise. This is an advantage only Shuttle-launched planetary probes enjoy.

The Venus Radar Mapper promises to yield new and important information about Venus. Its low cost heralds a new age in planetary exploration — cheaper and more versatile spacecraft. And most of them will depend on the Space Shuttle for transportation to work. (See "The Venus Radar Mapping Mission," ASTRONOMY, April 1983.)

Future Payloads

NASA is planning many more astronomy-oriented payloads for the future. All fields are represented — from solar physics and planetary science to deep-sky astronomy. Among the planned projects:

- The Solar Optical Telescope — enclosed in a 3.8-meter canister and mounted in the payload bay of the Shuttle, it will resolve features on the Sun as small as 70 km in visible wavelengths, and even smaller features in ultraviolet light. The telescope is scheduled to fly in 1989.
- The Shuttle Infrared Telescope Facility, also carried in the Shuttle's payload bay. The 0.85-meter telescope will have cryogenically cooled optics to detect objects 100 times fainter than those detected from the ground.
- A Shuttle-mounted radio astronomy antenna could contribute greatly to radio surveys of the sky. The Shuttle radio telescope would allow astronomers, for the first time, to extensively map radio sources in the southern hemisphere.
- The Shuttle may also be used to launch new planetary missions to the Moon, Mars, Venus, the asteroids, and the outer planets and their satellites. Among the projects proposed — a lunar geoscience orbiter, a Mars climatology/geoscience orbiter, and a Titan atmospheric probe/flyby mission.

The future is indeed bright for space-based astronomy. Standardized, economical spacecraft, in conjunction with the economical launch services provided by the Space Shuttle, should ensure a healthy, stable period of astronomical exploration. In fact, in the near future, astronomers will probably accompany their experiments aboard the Shuttle, since its spacious cabin provides room for up to seven occupants. Thanks to the Shuttle, astronomers can now routinely conduct astronomy where it should be conducted — from space!

Michael Engle is a payload flight design engineer for McDonnell Douglas Corporation at NASA's Johnson Space Center in Houston.

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ANNOUNCEMENT — The Astronomical Society of Kansas City meets on the fourth Sunday of each month. Meetings begin at 7:30 p.m. in room 103 of Royall Hall at the UMKC campus. Royall Hall is located between Rockhill Road and Holmes on 52nd Street. For information phone Gary Pittman at (816) 228-4238 or write the ASKC at P.O. Box 400, Blue Springs, MO 64015.

ANNOUNCEMENT — The recently founded International Federation of Astronomical Societies will bring together the talents, knowledge, and ideas of astronomers from around the world. We will have a central information and project dispersing body, from which the results of hundreds (thousands!) of observations and photos will be available for the asking. Anyone interested in astronomy, space, science, computers, etc., is welcome. If you have any questions or ideas, or would just like to help, please contact Gary Paul Anderson, 8191 Woodland Shore #12, Brighton, MI 48116; or Doug Kolonia, P.O. Box 247, Lowell, FL 32663.

ANNOUNCEMENT — Golden Jubilee Symposium to celebrate the 50th anniversary of the Sheffield Astronomical Society. April 7, 1984, at Friends Meeting House, Hartshead, Sheffield, England. Guest speakers, exhibition and trade stands. Admission fee of three pounds includes evening lecture, morning coffee, and afternoon tea. Contact Mrs. Nora Betts, Honorary Secretary, 35 Upper Albert Road, Sheffield S8 9HS, Yorkshire, England

ANNOUNCEMENTS — The Amateur Astronomers of Maryland will meet at the Hamilton Branch of the Enoch Pratt Library System, Baltimore, from 6:30 to 8:30 on March 21, April 18, June 20, and July 18. The May meeting will be determined later. Contact Robert Calhoon, P.O. Box 397, Chestertown, MD 21620, phone (301) 778-4809; or Doug Cook, 8072 Green Bud Lane, Apt. T-4, Glen Burnie, MD 21061, phone (301) 969-1622.

ANNOUNCEMENT — The ever-expanding Plutonian Society ("Exploring the Solar System and Beyond") is looking for new members. If you live in Asia, especially South Korea, contact me for more info. Larry N. Mooring, Det. 2, 1st Space Wing, USAG-T, APO San Francisco, CA 96218.

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ANNOUNCEMENT — The Plutonian Society is looking for individuals who like to share their views and dreams and astronomy with others. Write and read in the PLS on astronomy and other related things! Contact Doug Gerety, 2564 Holly Hedges, Apt. 3, Memphis, TN 38128.

ANNOUNCEMENT — The Northern New York Astronomical Society, a member of the Astronomical League, invites all interested persons to contact us. We offer monthly newsletters, star parties, meetings, study groups, public display projects, computer programming, telescope building, and more. Contact Pete Beaumont, President, N.N.Y.A.S., P.O. Box 106, Watertown, NY 13601. Phone (315) 788-2472.

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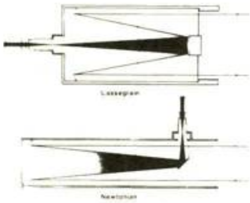

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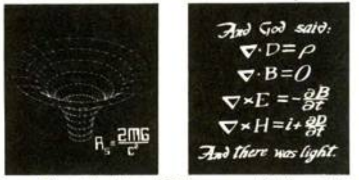
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WANTED — I'm looking for astronomical programs for the 1200XL Atari Computer. Contact Maria Th. Awal, Taukhid 71, Tulodong Bawah, Kebayoran Baru, Jakarta Selatan, Indonesia.

WANTED — Copy of the book *Starfall* by Betty Grissom and Henry Still. Contact David Fabrizio, 47 Benham Ave., Milford, CT 06460.

WANTED — Correspondence with anyone conducting solar observation at all stages who wishes to exchange notes. Contact Duane Baisley, 23 Becker St., Lake Peekskill, NY 10537.

WANTED — Any information regarding home-built motor drives for 10" f/5.6 Dobsonian mount. I am plunging into astrophotography. Contact George Goyena, 26 Herrero St., Dagupan City 0701, Philippines.

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WANTED — I'm looking for Apollo-Skylab-Shuttle VHS tapes. Am also looking for Meade model 1080 8" Schmidt-Cassegrain or a comparable unit. Contact Scott Beal, 6083 W. Broadway, New Hope, MN 55428. Phone (612) 533-3267.

FOR SALE — I'm cleaning house and must sell many back issues of ASTRONOMY, *Sky & Telescope*, *Scientific American*, *Natural History*, some books including science fiction, microscope, etc. Send SASE to S. Lopata, Box 234, W. Lebanon, NH. Phone (602) 448-2509 after 5 p.m.

FOR SALE — Meade Research Series #880 8" f/6 with casters, leveling screws, dust covers, accessory shelf, and manual declination control. Superb condition, $1200. Also, Lumicon ''Superfinder,'' 80mm F300mm with 1¼" star diagonal (30mm clear aperture) and 4½" straight extension tube and 30mm Lumicon 1¼" eyepiece. Already mounted on above telescope, $185. Will sell telescope without ''Superfinder'' but not vice versa. Phone (704) 254-5978 (nights) or (704) 253-0434 (days).

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FOR SALE — ASTRONOMY back issues, first issue through December 1981, $275 or best offer. Contact J. Hutton, 12235 S.E. 62nd St., Bellevue, WA 98006.

FOR SALE — Dynamax 8, drive corrector, three lenses. Very good condition, $600 plus shipping. Contact Dan Sharpe, 4 Archie St., Chicopee, MA 01020.

FOR SALE — *Sky & Telescope* back issues, June 1965 through June 1982 complete. In good condition, $200 plus shipping. Contact Dale Feldmann, 1505 W. Pittsburg St., Broken Arrow, OK 74012. Phone (918) 251-0756.

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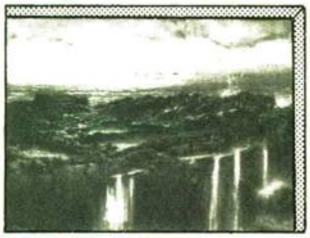

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FOR SALE — Meade 80mm Photo Guide telescope with mounting rings, $175. Meade telescope tube, 15" I.D. x 60" with end rings and 12½" mirror mount, $110. Novak research grade spider for 14¾" to 15¾" I.D. tube, $10. 3.10" diagonal holder for above, $10. All in mint condition, never used. Contact Steve Timko, 66 Lake St., Belleville, NJ 07109. Phone (201) 759-5790.

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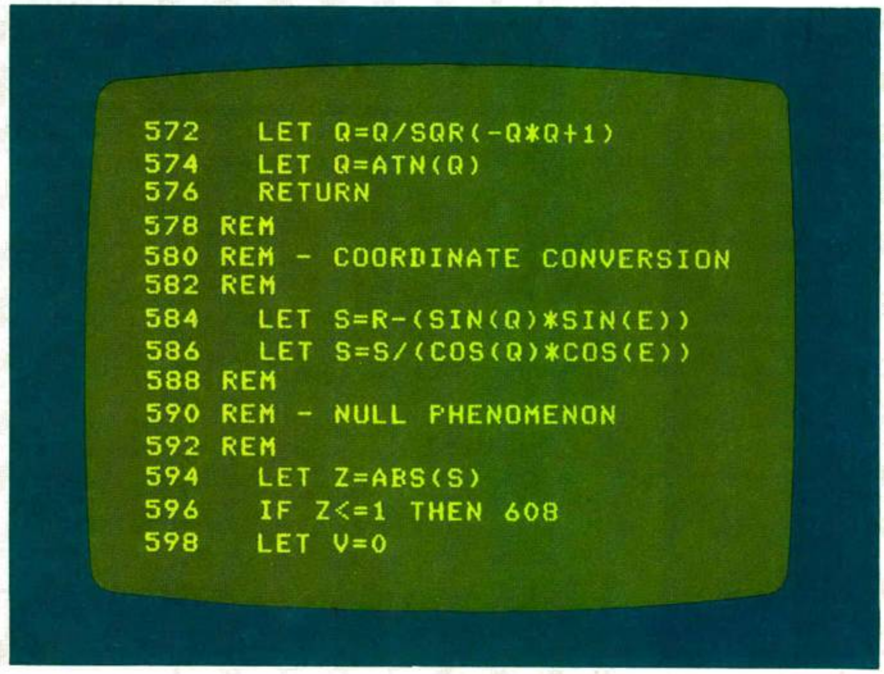


```
572    LET Q=Q/SQR(-Q*Q+1)
574    LET Q=ATN(Q)
576    RETURN
578 REM
580 REM - COORDINATE CONVERSION
582 REM
584    LET S=R-(SIN(Q)*SIN(E))
586    LET S=S/(COS(Q)*COS(E))
588 REM
590 REM - NULL PHENOMENON
592 REM
594    LET Z=ABS(S)
596    IF Z<=1 THEN 608
598    LET V=0
```

My astronomical software library is fairly extensive, but one program is the hands-down favorite with nearly everyone. Its name is SUNNY.BAS. It calculates the times of sunrise, sunset, and civil, nautical, and astronomical twilight based on the formulas found in the U.S. Naval Observatory's *Almanac for Computers*. My friends say they enjoy running it during the evening newscast and are tickled to get the same results as the TV weatherman.

"SUNNY" is coded in a rudimentary form of BASIC to enhance its machine independence. I have tested it on micros, minis, and mainframes, on machines as diverse as a TRS-80 Pocket Computer and a DECsystem-10. Particular attention was paid to having it run under Microsoft BASIC on a personal computer. In developing it, whenever I've found a quirk on one machine, I have reprogrammed "SUNNY" on all of the other machines in an even more general form. I believe this program will run, as is, on nearly any computer. This version of SUNNY.BAS does not even call the TAN function — I have replaced it by dividing the SIN by the COS of an angle.

If your machine has enough memory, key in the REMark lines along with the rest of the program even if it seems like a lot of extra work. The remarks will answer your questions should you lose this copy of ASTRONOMY, and you can provide documented copies of the program for your friends, even if they've never seen this article. Poorly documented software is nothing but a headache!

(Only if you will be running the program on Radio Shack's Pocket Computer must you change anything. That machine has a square-root key instead of the SQR function. Also, because of its 1.4K memory limitation, you can calculate only sunrise and sunset and have to expunge the REM statements. Users should be aware that RAD mode must be set.)

The program correctly reproduces the answer to the sample problem in the *Almanac for Computers*, a myriad of entries in recent editions of the *Astronomical Almanac*, and the times given on local newscasts. An error of a minute or so is not uncommon, but striving for higher accuracy is unwarranted because the Sun takes approximately three minutes to set and the times of dawn and dusk vary according to atmospheric conditions.

As it stands, if you key SUNNY in exactly as reproduced here, you stand a good chance of having it work correctly the very first time. However, before you show it off for your friends, try a test run and compare your answers with the ones shown below.

After you type RUN, SUNNY will ask for your latitude in degrees, minutes, and seconds of arc. Milwaukee is 43° 4′ north, so we typed 43.04. We didn't supply seconds of arc, but if we had known our latitude to seconds of arc and wanted to type them, seconds would have been two more digits, thus: 43.0400. For locations south of the equator, enter the latitude as a negative number.

Next we supplied our longitude: 87° 58′ west of Greenwich, England, right from an atlas. Once again, we must separate the degrees from the minutes and seconds by a decimal point: 87.58. If you know your longitude to the nearest second of arc, instead of the nearest minute of arc, just add the extra digits: 92.3359 represents 92° 33′ 59″. Longitudes measured east of Greenwich are entered as negative numbers.

SUNNY next asks: "ZONE ?" You must supply your time zone in hours west of Greenwich. The standard time zones in the United States are: Eastern, 5; Central, 6; Mountain, 7; Pacific, 8. During the summer, when daylight time is in effect, they become: Eastern, 4; Central, 5; Mountain, 6; and Pacific, 7. If you live in part of the world with half-hour time zones, enter both hours and minutes, thus: 11.30.

Finally, SUNNY requires the year (all

four digits), the month as a number from 1 through 12, and the day of the month. As soon as you hit the *enter* or *carriage return* key for the day, SUNNY goes to work. Here's our sample run:

```
RUN

      LAT.    ? 43.04
      LON.    ? 87.58
      ZONE    ? 5
      YEAR    ? 1984
      MONTH   ? 6
      DAY     ? 20

      A DAWN      2.53
      N DAWN      3.51
      C DAWN      5.56
      SUNRIS      5.12
      SUNSET     20.35
      C DUSK     21.10
      N DUSK     21.56
      A DUSK     22.54

      ------------------------------

      YEAR    ? 1984
      MONTH   ? 12
      DAY     ? 20

      A DAWN      6.37
      N DAWN      7.12
      C DAWN      9.06
      SUNRIS      8.20
      SUNSET     17.20
      C DUSK     17.52
      N DUSK     18.28
      A DUSK     19.03

      ------------------------------

      YEAR    ? 1984
      MONTH   ? 3
      DAY     ? 20

      A DAWN      5.18
      N DAWN      5.52
      C DAWN      7.31
      SUNRIS      6.54
      SUNSET     19.05
      C DUSK     19.34
      N DUSK     20.07
      A DUSK     20.41

      ------------------------------

^C
Ok
```

Did you get the same results? If you did, chances are that you made no errors when you keyed in the program. If you get wildly different results, you'll have to debug the program, a task we'll leave to you. If your results are only slightly different, check *all the numerical* constants.

What do these numbers mean? The first, "A DAWN," is the beginning of astronomical twilight — the time when the sky first glows a little bit brighter in the east. To display this time, the program instructs the computer to determine when the Sun is 108° from the zenith, or 18° below the horizon.

Next comes "N DAWN," or the beginning of nautical twilight, when the Sun is 12° below the horizon, or 102° from the zenith. For an amateur astronomer, the onset of nautical twilight marks the end of the night for most kinds of observing. Of course, lunar and planetary observers can still view their bright targets, but faint objects will soon be lost.

The beginning of civil twilight, "C DAWN," means that if you're driving, it's become bright enough to turn off your headlights.

"SUNRIS" is the time of sunrise. The program computes the time when the center of the Sun is 90°50′ from the zenith, which, under normal conditions of temperature and humidity, means that the upper limb of the Sun is then on the horizon for a sea-level observer. But don't worry about those fine points unless you're on top of a mountain 29,000 feet high, enjoying sunrise on a crisp, clear morning that's 60 below zero in air that's dry as a bone. SUNNY might then be off by half a minute or so.

"SUNSET," "C DUSK," "N DUSK," "A DUSK" are the evening equivalents of the morning phenomena, but the times are given for a 24-hour clock, so 16.00 means 4:00 p.m.

Go ahead and try the program for different times of the year and parts of the world, but remember that the accuracy suffers when the Sun is close to the horizon for long periods of time. By the way — if the Sun doesn't set at all, or if the sky never darkens fully, SUNNY prints a "0" for the phenomena that don't occur. Handy advice to those in the lands of the midnight Sun.

How does it work? SUNNY begins by converting each of your inputs into decimal hours (instead of hours, minutes, and seconds) and converting them to radian measure. It computes the day-of-year value from a clever algorithm given

```
100 REM PURPOSE --
102 REM
104 REM  THIS PROGRAM GIVES THE TIME OF
106 REM  SUNRISE, SUNSET, AND TWILIGHT
108 REM  (ASTRONOMICAL, NAUTICAL, AND
110 REM  CIVIL) TO WITHIN A MINUTE OR
112 REM  TWO DURING THE SECOND HALF OF
114 REM  THE TWENTIETH CENTURY.
116 REM
118 REM INPUTS --
120 REM
122 REM  LATITUDE IN DEGREES, MINUTES,
124 REM  AND SECONDS. NORTH IS POSITIVE.
126 REM  EXAMPLE: 30.0028 REPRESENTS 30
128 REM  DEGREES, 00 MINUTES, 28 SECONDS
130 REM  NORTH LATITUDE.
132 REM
134 REM  LONGITUDE IN DEGREES, MINUTES,
136 REM  AND SECONDS. WEST IS POSITIVE.
138 REM  EXAMPLE: 90.1109 REPRESENTS 90
140 REM  DEGREES, 11 MINUTES, 09 SECONDS
142 REM  WEST LONGITUDE.
144 REM
146 REM  TIME ZONE IN HOURS AND MINUTES
148 REM  THAT ARE ADDED TO WALL CLOCK
150 REM  TIME TO YIELD UNIVERSAL TIME.
152 REM  IN THE FORTY-EIGHT CONTIGUOUS
154 REM  UNITED STATES, SEE TABLE BELOW.
156 REM
158 REM                STANDARD  DAYLIGHT
160 REM
162 REM    EASTERN       5.00       4.00
164 REM    CENTRAL       6.00       5.00
166 REM    MOUNTAIN      7.00       6.00
168 REM    PACIFIC       8.00       7.00
170 REM
172 REM  YEAR (1951 THRU 2000)
174 REM
176 REM  MONTH (1 THRU 12)
178 REM
180 REM  DAY (1 THRU 31)
182 REM
184 REM OUTPUTS --
186 REM
188 REM  OUTPUTS ARE GIVEN IN HOURS AND
190 REM  MINUTES ON A TWENTY-FOUR HOUR
192 REM  BASIS. EXAMPLE: 6.25 REPRESENTS
194 REM  6:25 A.M., AND 18.25 REPRESENTS
196 REM  6:25 P.M.
198 REM
200 REM  A ZERO OUTPUT INDICATES THAT
202 REM  THE PHENOMENON DOES NOT OCCUR
204 REM  ON THE SPECIFIED DATE, E.G.,
206 REM  THE SUN DOES NOT SET IN MID-
208 REM  SUMMER AT HIGH LATITUDES.
210 REM
212 REM SAMPLE --
214 REM
216 REM  LAT
218 REM  ? 30
220 REM  LON
222 REM  ? 90
224 REM  ZONE
226 REM  ? 5
228 REM  YEAR
230 REM  ? 1983
232 REM  MONTH
234 REM  ? 5
236 REM  DAY
238 REM  ? 19
240 REM
242 REM  A DAWN  4.33
244 REM  N DAWN  5.06
246 REM  C DAWN  5.38
248 REM  SUNRIS  6.04
250 REM  SUNSET  19.49
252 REM  C DUSK  20.15
254 REM  N DUSK  20.47
256 REM  A DUSK  21.21
258 REM
260 REM -----------------------------
262 REM
264 REM - CONSTANTS
266 REM
268    LET A=1.5708
270    LET B=3.14159
272    LET C=4.71239
274    LET D=6.28319
276 REM
278 REM - INPUTS
280 REM
282    PRINT 'LAT'
284    INPUT Z
286    GOSUB 452
288    LET E=Z*1.74533E-2
290 REM
292    PRINT 'LON'
294    INPUT Z
296    GOSUB 452
298    LET F=Z*1.74533E-2
300 REM
302    PRINT 'ZONE'
304    INPUT Z
306    GOSUB 452
308    LET G=Z*2.61799F-1
310 REM
312    PRINT 'YEAR'
314    INPUT H
316 REM
318    PRINT 'MONTH'
320    INPUT I
322 REM
324    PRINT 'DAY'
326    INPUT J
328 REM
330 REM - DAY OF YEAR
332 REM
334    LET K=INT((I+9)/12)
336    LET X=H/4
338    LET Y=INT(X)
340    LET Z=X-Y
342    IF Z=0 THEN 346
344    LET K=K*2
346    LET H=INT(275*I/9)
348    LET H=H+J-K-30
350 REM
352 REM - RISING PHENOMENA
354 REM
356    PRINT ' '
```

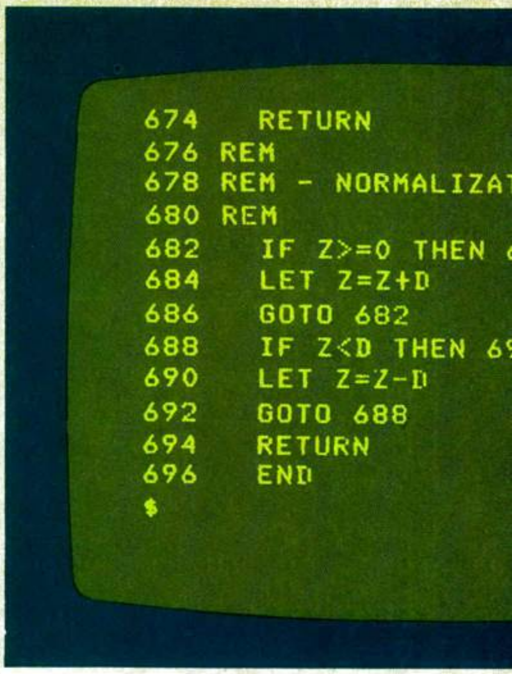
in the *Almanac for Computers*, then adds the approximate time of the event to that. The heavy stuff starts when SUNNY computes the Sun's mean anomaly for the time, obtains the true longitude in ecliptic coordinates, then converts that to the Sun's R.A. and Dec.

Next it evaluates the hour angle of the Sun for cosine zenith distances of 90°50', 96°, 102°, and 108°. R is the variable assigned to that cosine. Lastly, that time gets converted, via the time of year and your time zone, into local time, then converts into and prints it in hours and minutes format.

There are plenty of subroutine calls in this program, which makes SUNNY hard to follow — but it could be a lot more compact. If you *really* want to know what goes on in SUNNY, borrow a copy of *Almanac for Computers 1984* from your library, or order a copy direct. The address is: Administrative Division, United States Naval Observatory, Washington, DC, 20390. It costs $5.00 including postage; make your check payable to the United States Naval Observatory. This book is a real eye-opener, but is not intended for the mathematically faint-hearted!

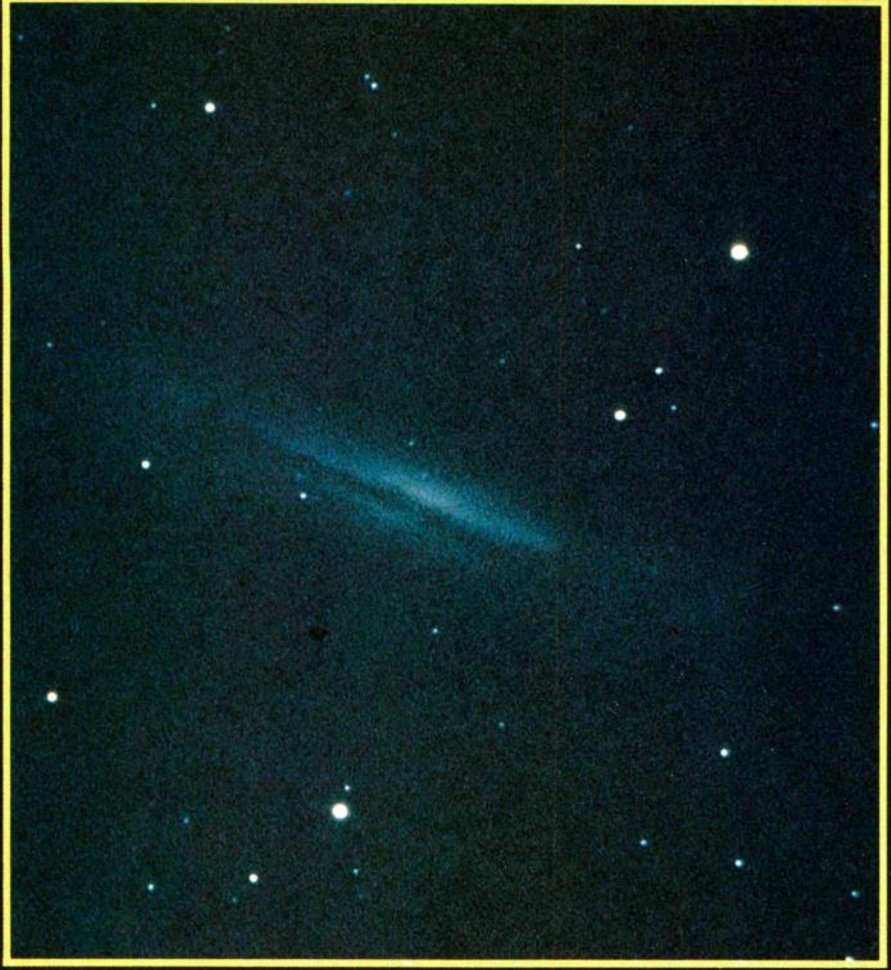
As a program, SUNNY.BAS isn't very satisfying, but it is useful. You can make it much more efficient and elegant, I am sure, if you tailor it to your own specific computer, add graphics, or convert it to a subroutine as part of a more general program.

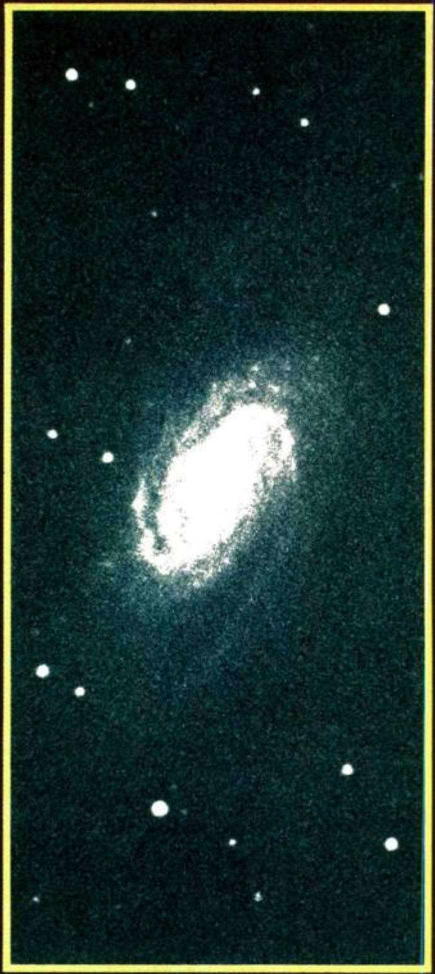
Editor's Note: We have received so many programs from readers this year that we're convinced you're all indoors with your computers instead of outdoors with your telescopes. Programs sent to ASTRONOMY must be fully documented and must not rely on machine-specific features. Because of the number of program submissions we now receive, we do not acknowledge individual submissions — but we do wish to express our thanks to all the readers who have submitted material.

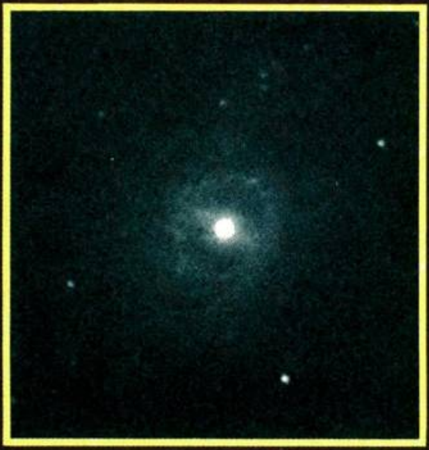


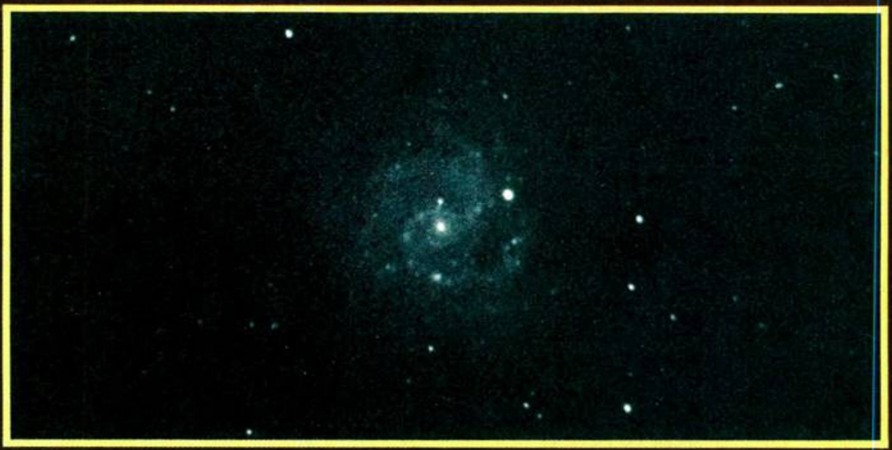
```
674    RETURN
676 REM
678 REM - NORMALIZA
680 REM
682    IF Z>=0 THEN 6
684    LET Z=Z+D
686    GOTO 682
688    IF Z<D THEN 69
690    LET Z=Z-D
692    GOTO 688
694    RETURN
696    END
$
```

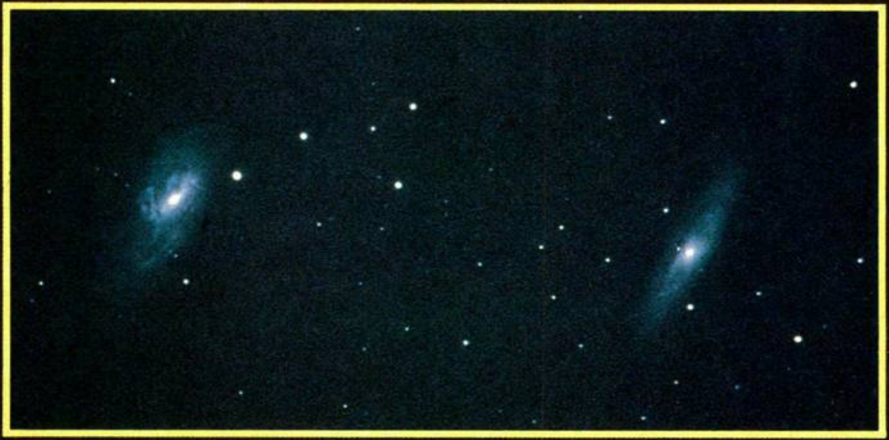
```
358 REM
360    LET I=0
362    LET J=A
364    GOSUB 478
366 REM
368    LET R=-3.09017E-1
370    GOSUB 584
372    PRINT "A DAWN ";V
374 REM
376    LET R=-2.07912E-1
378    GOSUB 584
380    PRINT "N DAWN ";V
382 REM
384    LET R=-1.04528E-1
386    GOSUB 584
388    PRINT "C DAWN ";V
390 REM
392    LET R=-1.45439E-2
394    GOSUB 584
396    PRINT "SUNRIS ";V
398 REM
400 REM - SETTING PHENOMENA
402 REM
404    LET I=1
406    LET J=C
408    GOSUB 478
410 REM
412    LET R=-1.45439E-2
414    GOSUB 584
416    PRINT "SUNSET ";V
418 REM
420    LET R=-1.04528E-1
422    GOSUB 584
424    PRINT "C DUSK ";V
426 REM
428    LET R=-2.07912E-1
430    GOSUB 584
432    PRINT "N DUSK ";V
434 REM
436    LET R=-3.09017E-1
438    GOSUB 584
440    PRINT "A DUSK ";V
442 REM
444    GOTO 696
446 REM
448 REM - SEXAGESIMAL TO DECIMAL
450 REM
452    LET W=1
454    IF Z>=0 THEN 460
456    LET W=-1
458    LET Z=ABS(Z)
460    LET X=INT(Z)
462    LET Z=(Z-X)*100
464    LET Y=INT(Z)
466    LET Z=(Z-Y)*100
468    LET Z=(X+Y/60+Z/3600)*W
470    RETURN
472 REM
474 REM - APPROXIMATE TIME
476 REM
478    LET K=H+((J+F)/D)
480 REM
482 REM - SOLAR MEAN ANOMALY
484 REM
486    LET L=K*1.7202E-2
488    LET L=L-5.74039E-2
490 REM
492 REM - SOLAR TRUE LONGITUDE
494 REM
496    LET Z=SIN(L)
498    LET M=L+3.34405E-2*Z
500    LET Z=SIN(2*L)
502    LET M=M+3.49066E-4*Z
504    LET M=M+4.93289
506 REM
508 REM - QUADRANT DETERMINATION
510 REM
512    LET Z=M
514    GOSUB 682
516    LET M=Z
518    LET X=M/A
520    LET Y=INT(X)
522    LET Z=X-Y
524    IF Z<>0 THEN 528
526    LET M=M+4.84814E-6
528    LET N=2
530    IF M>C THEN 544
532    LET N=1
534    IF M>A THEN 544
536    LET N=0
538 REM
540 REM - SOLAR RIGHT ASCENSION
542 REM
544    LET P=SIN(M)/COS(M)
546    LET P=ATN(.91746*P)
548 REM
550 REM - QUADRANT ADJUSTMENT
552 REM
554    IF N=0 THEN 570
556    IF N=2 THEN 562
558    LET P=P+B
560    GOTO 570
562    LET P=P+D
564 REM
566 REM - SOLAR DECLINATION
568 REM
570    LET Q=.39782*SIN(M)
572    LET Q=Q/SQR(-Q*Q+1)
574    LET Q=ATN(Q)
576    RETURN
578 REM
580 REM - COORDINATE CONVERSION
582 REM
584    LET S=R-(SIN(Q)*SIN(E))
586    LET S=S/(COS(Q)*COS(E))
588 REM
590 REM - NULL PHENOMENON
592 REM
594    LET Z=ABS(S)
596    IF Z<=1 THEN 608
598    LET V=0
600    RETURN
602 REM
604 REM - ADJUSTMENT
606 REM
608    LET S=S/SQR(-S*S+1)
610    LET S=-ATN(S)+A
612    IF I=1 THEN 622
614    LET S=D-S
616 REM
618 REM - LOCAL APPARENT TIME
620 REM
622    LET Z=1.72028E-2*K
624    LET T=S+P-Z-1.73364
626 REM
628 REM - UNIVERSAL TIME
630 REM
632    LET U=T+F
634 REM
636 REM - WALL CLOCK TIME
638 REM
640    LET V=U-G
642 REM
644 REM - DECIMAL TO SEXAGESIMAL
646 REM
648    LET Z=V
650    GOSUB 682
652    LET Z=Z*3.81972
654    LET V=INT(Z)
656    LET W=(Z-V)*60
658    LET X=INT(W)
660    LET Y=W-X
662    IF Y<.5 THEN 666
664    LET X=X+1
666    IF X<60 THEN 672
668    LET V=V+1
670    LET X=0
672    LET V=V+X/100
674    RETURN
676 REM
678 REM - NORMALIZATION
680 REM
682    IF Z>=0 THEN 688
684    LET Z=Z+D
686    GOTO 682
688    IF Z<D THEN 694
690    LET Z=Z-D
692    GOTO 688
694    RETURN
696    END
$
```











Top left: NGC-3628 in Leo is a spiral galaxy turned almost edge-on. The broad dust lane in its plane cuts across the nuclear bulge. Photo by Jack Newton. Top right: NGC-2903 (also in Leo) is seen close to face-on; its spiral arms delineated by lanes of dust stand out clearly in this photo by Martin Germano. Above left: M-95 is a barred spiral galaxy in Leo resembling a Greek theta; photo by Martin Germano. Above right: NGC-3184 (in Leo) is a faint spiral galaxy tilted so that we are looking down onto its disk. Photo by Martin Germano. Left: M-65 and M-66 in Leo form a pretty pair in Jack Newton's photo. Both galaxies have bright nuclei surrounded by a faint haze difficult to see in small instruments.

Leo

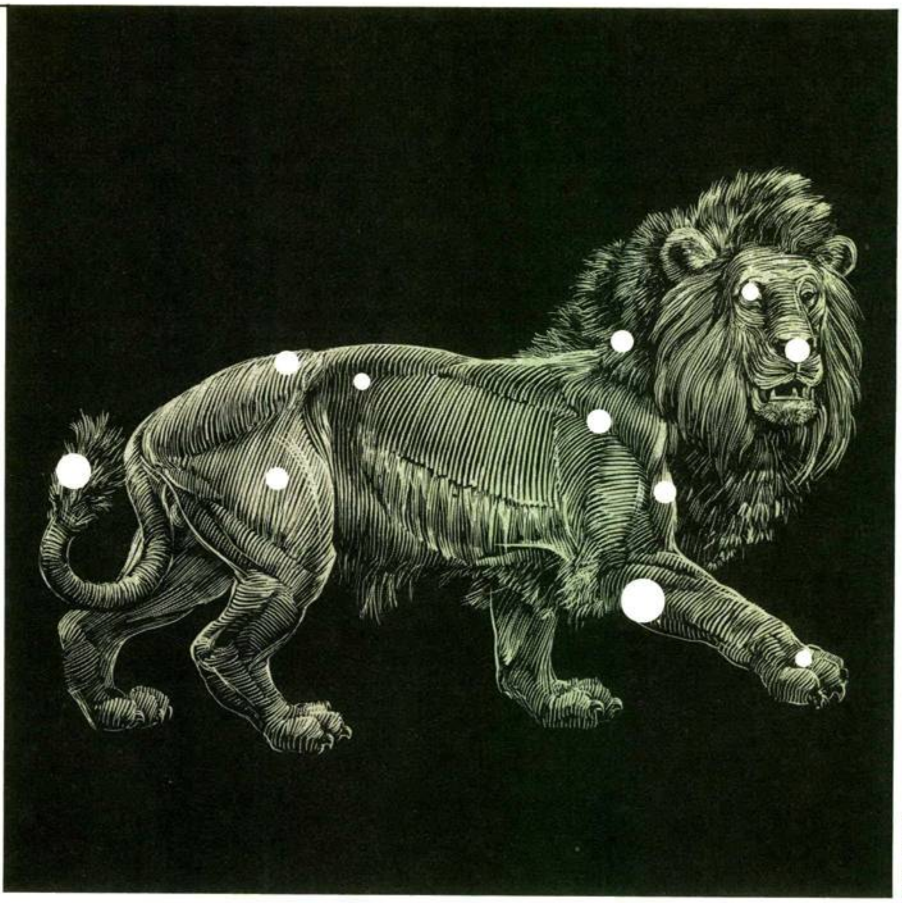
Leo
Leonis

Leo Minor

LMi
Leonis Minoris

Sextans

Sex
Sextantis



Keith Ward

The constellations **Leo** the Lion, **Leo Minor** the Little Lion, and **Sextans** the Sextant encompass a region of sky with lots of a single type of deep-sky object — galaxies. Though many 9th and 10th magnitude spirals dominate the scene, there is also room left for the occasional double star to test your optics and variable star to test your eye's keenness.

The brightest galaxy in Leo — located about 1.5° south of Lambda (λ) Leonis — is **NGC-2903**, a large, loosely wound spiral, which shines at magnitude 9.5. Its dimensions of 11.0′ x 4.7′ make it visible as a tiny smudge even in a 2-inch telescope; a 4-inch at high power shows a mottled oval core surrounded by a tenuous haze. Eight-inch telescopes on good nights show this galaxy's condensed nucleus encapsulated in a vast halo of faint nebulosity, including mottled dark areas indicating dust in the spiral arms. The distance to this great spiral is 7 megaparsecs (Mpc); its mass is on the order of 43 billion solar masses.

Almost as luminous as NGC-2903 is the Sb-type spiral **M-66** (NGC-3627), which glows at magnitude 9.7 and is the kingpin of a group of three bright galaxies clustered in one telescopic field. Midway between the stars Theta (θ) and Iota (ι) Leonis — about 2.5° south-southeast of θ — lie M-66, **M-65** (NGC-3623), and **NGC-3628**. M-66 measures 8.0′ x 2.5′ across and is visible in finder telescopes on dark nights, appearing as a tiny patch of fuzz. Larger telescopes show a bright elongated region of grey nebulosity wrapped in a fainter halo; 10-inch scopes hint at spiral structure. The galaxy M-65 is a type Sa/Sb and appears much flatter, measuring 7.8′ x 1.6′. Its magnitude of 10.2 keeps its surface brightness fairly high, so small telescopes reveal it as a silvery disk of light viewed close to edge-on — something like seeing an illuminated quarter-dollar from far away. The thin bright disk portion of M-65 shows up in all telescopes, but you'll need a good 8-incher to see much of the galaxy's perimeter, composed of a lightly mottled haze. M-65 and M-66 lie 21′ apart in the sky, corresponding to about 55 kpc; they measure 18.3 kpc and 15.4 kpc across, respectively, and their distance from Earth is around 9.7 Mpc.

The third member of the trio of galaxies that form the core of the M-65 group is NGC-3628, a large, faint galaxy aligned edge-on to our line of sight. Lying just 35′ north of M-66, it is one of the sky's best edge-on galaxies, though its surface brightness is considerably lower than NGC-4565 in Coma Berenices. Nevertheless, a good 6-inch reflector at high power shows the magnitude 10.3 disk intertwined with a thin but obvious dust band running along the galaxy's edge.

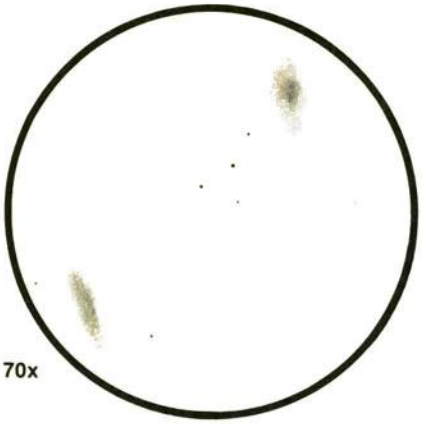
The second bright trio of galaxies in Leo is the group consisting of **M-95** (NGC-3351), **M-96** (NGC-3368), and **M-105** (NGC-3379). The brightest of the three is M-96, which glows at magnitude 10.1 and measures 6.0′ x 4.0′ across; its tight structure is elusive in telescopes, but an oval core is visible even in a good 3-incher. An 8-inch scope at high power begins to show some outer low-surface-brightness nebulosity. About 42′ west of M-96 is the small barred spiral system M-95; it shines at magnitude 10.5 and spans 4.0′ x 3.0′. This system is composed of a bright small core surrounded by a smooth bar that extends out to an encircling ring of matter. The galaxy's core and even its bar structure are relatively easy marks for medium-sized backyard telescopes on nights of good transparency; the outer ring structure, however, has a dismally low surface brightness. The distance to these two galaxies is about 8.9 Mpc.

About 48′ north-northwest of M-96 is the elliptical galaxy M-105. This little ball of fuzz measures only 2.1′ x 2.0′ across and shines at magnitude 10.3; it is visually unimpressive compared with the spirals in Leo. Being an elliptical, it has a high surface brightness, but doesn't show any detail, regardless of the telescope used. This galaxy lies 130 kpc from M-95 and M-96. The faint galaxies NGC-3384 and NGC-3389 (magnitudes 11.0 and 12.2, respectively) form a little triangle with M-105, which measures about 8′ on a side. See if you can pick up all three in a low-power eyepiece field.

A large, impressive spiral galaxy is

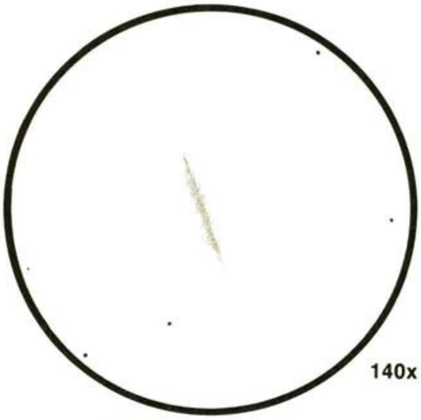
For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

M-65 & M-66



NGC-3115

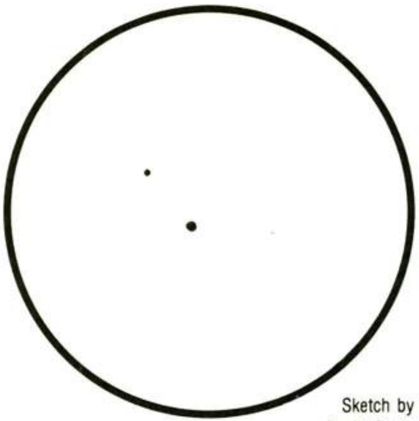
8-inch SCT



Sketches by David J. Eicher

Regulus

8-inch SCT
222x



Sketch by
David Godin

NGC-3521, located in the far southern reaches of Leo. This is a good example of a tightly wound multi-arm spiral of type Sb; its magnitude is 9.6, and its dimensions 6.0′ x 4.0′. Affix a low-power ocular when sweeping to find this galaxy, and you'll note a bright, obvious streak of grey misty light. A 4-inch telescope using medium powers clearly reveals an elongated shape around a condensed core of bright nebulosity. An 8-incher shows this, as well as some of the hazy envelope of low surface brightness nebulosity composing the galaxy's spiral arms.

The Lion contains some good double and variable stars as well as innumerable galaxies. One of the most popular doubles is **Regulus** (Alpha [α] Leonis), the brightest star in this swath of sky. Regulus means "the little king," and it is a fitting title for the 1.4 magnitude star whose secondary — shining at magnitude 7.9 and located 177″ away in p.a. 307° (1924) — is an easy-to-find, attractive sight in small telescopes. Regulus is about 26 pc distant, and shines with the luminosity of 160 Suns. A curious object only 20′ north of Regulus is the dwarf elliptical galaxy known as **Leo I**, one of the smallest and faintest known galaxies and — at a distance of 230 kpc — a member of the Local Group. On photographic plates it appears as a smudge about 10′ across; Regulus' glare and the galaxy's low surface brightness make it extremely difficult to observe visually.

A fine double star is **Algeiba** (Gamma [γ] Leonis), a magnitude 2.0 system including 2.1 and 3.4 magnitude stars separated by 4.4″ in p.a. 123° (1966). First find this star, the brightest in the "Sickle" of Leo, by moving 8° north and slightly east from Regulus. You can then increase your telescopic magnification to the point where the double is cleanly split.

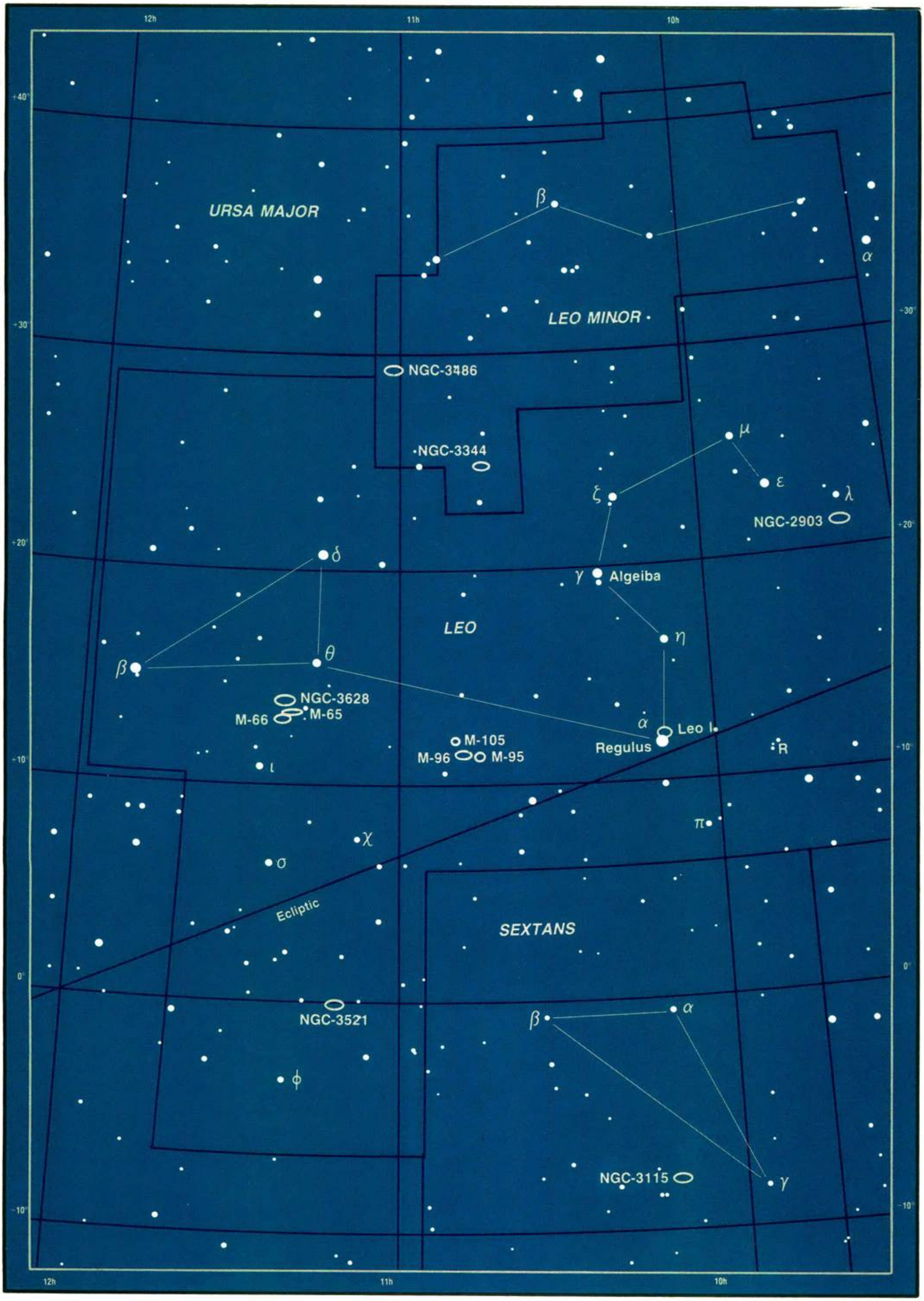
Nearly due west of Regulus is the Mira-type star **R Leonis**, a long-period variable with a cycle of 312 days. The fourth known LPV, discovered by J.A. Koch in 1782, this star ranges from magnitude 5.2 to 10.5. Fortunately, R Leonis is bracketed by some very useful comparison stars — one shining around 5th magnitude and, closer yet, a pair of 11th magnitude stars forming a triangle with the variable. When you train your scope on this star, do you see a pair of bright stars surrounded by fainter ones or a solitary bright star accompanied by a triangle of fainter ones? The former indicates R Leo near its maximum, the latter near minimum.

The area of sky immediately surrounding Leo incorporates some fine galaxies, one of which is **NGC-3115** in Sextans. This is a 10th magnitude edge-on spindle galaxy, which shows as a slender streak of grey light in most backyard telescopes. Although it measures 4.0′ x 1.0′ in extent, this galaxy does not show much detail in backyard telescopes. **NGC-3344**, a galaxy in Leo Minor, is an magnitude 10.4 face-on late-type spiral, measuring 6.0′ x 5.1′ across and offering fine views to medium-sized telescopes. An 8-incher shows a soft glow surrounding a stellar nucleus. **NGC-3486**, also a resident of Leo Minor, is a multi-arm spiral measuring 5.5′ x 4.2′ and glowing at magnitude 10.8. Small telescopes show it as a circular haze with little detail of its inner workings.

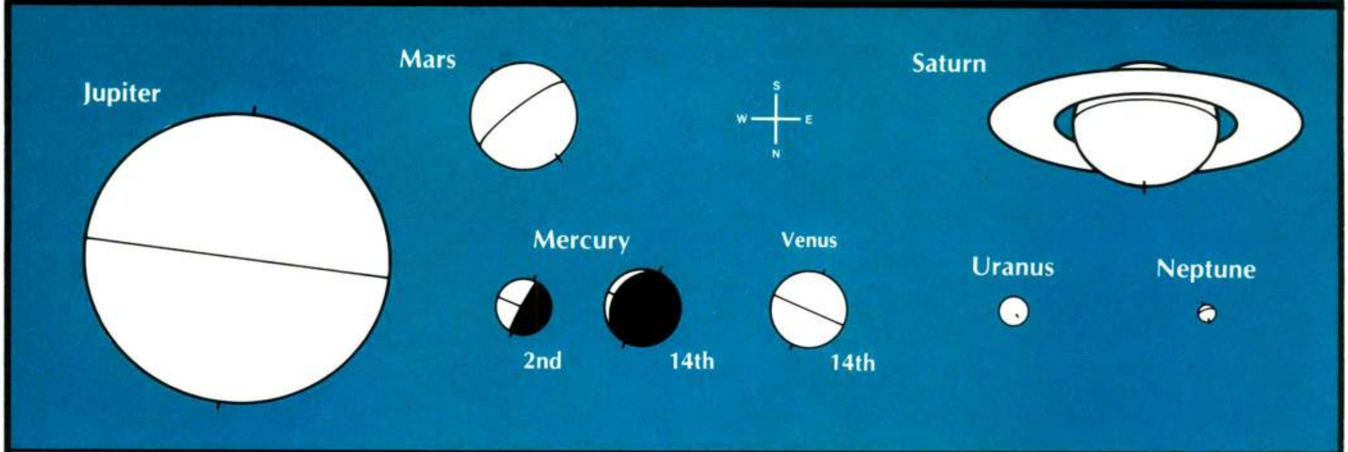
Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	H
NGC-2903		∮	9h 32m	+21°27′	9.5	11.0′x4.7′	Sb/Sc
R Leo		LPV	9h 48m	+11°26′	5.2↔10.5	312d	
NGC-3115		0L	10h 05m	−07°43′	10.0	4.0′x1.0′	E7/S0
Regulus (α Leo)		★^{2}	10h 08m	+11°58′	1.5,8.0	177″	
Leo I		0	10h 09m	+12°17′	11.1	11′x8′	E4
Algeiba (γ Leo)		★^{2}	10h 20m	+19°51′	2.5,3.5	4.4″	
NGC-3344		∮	10h 43m	+24°54′	10.5	6.0′x5.1′	Sc
NGC-3351	M-95	∮B	10h 44m	+11°42′	10.5	4.0′x3.0′	SBb
NGC-3368	M-96	∮	10h 47m	+11°49′	10.1	6.0′x4.0′	Sb
NGC-3379	M-105	0	10h 48m	+12°35′	10.3	2.1′x2.0′	E1
NGC-3486		∮	11h 01m	+28°59′	10.9	5.5′x4.2′	Sc
NGC-3521		∮	11h 06m	−00°02′	9.6	6.0′x4.0′	Sb
NGC-3623	M-65	∮	11h 19m	+13°07′	10.2	7.8′x1.6′	Sa/Sb
NGC-3627	M-66	∮	11h 20m	+13°01′	9.7	8.0′x2.5′	Sb
NGC-3628		∮	11h 20m	+13°36′	10.3	12.0′x2.0′	Sb

H = Hubble classification type for galaxies

★^{2}	*Double Star*
LPV	*Long Period Variable*
∮	*Spiral Galaxy*
0	*Elliptical Galaxy*
∮B	*Barred Spiral Galaxy*
0L	*Lenticular Galaxy*


12h
11h
10h
+40°
+30°
+20°
+10°
0°
-10°
URSA MAJOR
LEO MINOR
β
α
NGC-3486
NGC-3344
μ
ε
ζ
λ
NGC-2903
δ
γ
Algeiba
LEO
η
β
θ
NGC-3628
M-66
M-65
α
Leo I
Regulus
M-105
M-96
M-95
R
ι
π
χ
σ
Ecliptic
SEXTANS
NGC-3521
β
α
ϕ
NGC-3115
γ

Planetary Data April 1984


Jupiter
Mars
S
W
E
N
Saturn
Mercury
Venus
Uranus
Neptune
2nd
14th
14th

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun		1	−26.7	32.1′	—	1.00	—	—	11°27.7′	0h 42.9m	+ 4°36.9′
		15	−26.7	31.9′	—	1.00	—	—	25°13.2′	1h 34.3m	+ 9°50.2′
		30	−26.7	31.8′	—	1.01	—	—	39°50.5′	2h 30.6m	+14°49.9′
Mercury	☿	1	−0.3	7.2″	49%	0.94	0.32	121°23.1′	29°30.5′	1h 49.8m	+13°45.9′
		15	+2.9	10.6″	7%	0.64	0.40	187°28.6′	35°43.2′	2h 12.4m	+16°21.7′
		30	+3.2	11.6″	6%	0.58	0.46	235°30.2′	27°02.4′	1h 44.0m	+10°00.2′
Venus	♀	1	−3.9	10.6″	94%	1.58	0.73	323°42.1′	351°05.9′	23h 32.1m	− 4°34.9′
		15	−3.9	10.2″	96%	1.63	0.73	345°53.5′	8°21.3′	0h 35.6m	+ 2°11.6′
		30	−3.9	10.0″	98%	1.67	0.73	9°44.5′	26°49.4′	1h 44.1m	+ 9°19.5′
Mars	♂	15	−1.1	14.6″	97%	0.64	1.58	217°47.8′	237°09.3′	15h 43.9m	−18°49.1′
Jupiter	♃	15	−2.3	39.9″	99%	4.94	5.25	271°52.6′	282°06.6′	18h 55.7m	−22°37.2′
Saturn	♄	15	+0.2	18.6″	100%	8.90	9.86	222°30.5′	223°56.5′	14h 51.9m	−13°44.8′
Uranus	⛢	15	+5.5	3.8″	100%	18.32	19.01	250°59.5′	252°42.6′	16h 48.3m	−22°22.6′
Neptune	♆	15	+7.9	2.2″	100%	29.84	30.26	269°38.9′	270°52.1′	18h 06.9m	−22°13.9′
Pluto	♇	15	+13.7	0.1″	100%	28.88	29.83	210°42.6′	210°26.3′	14h 20.0m	+ 4°30.9′

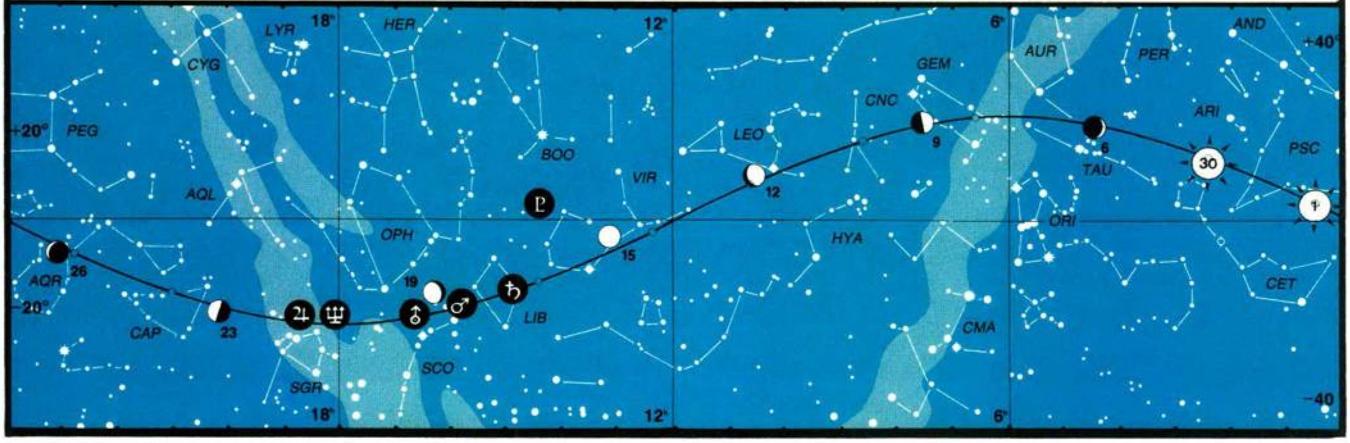
Universal Time

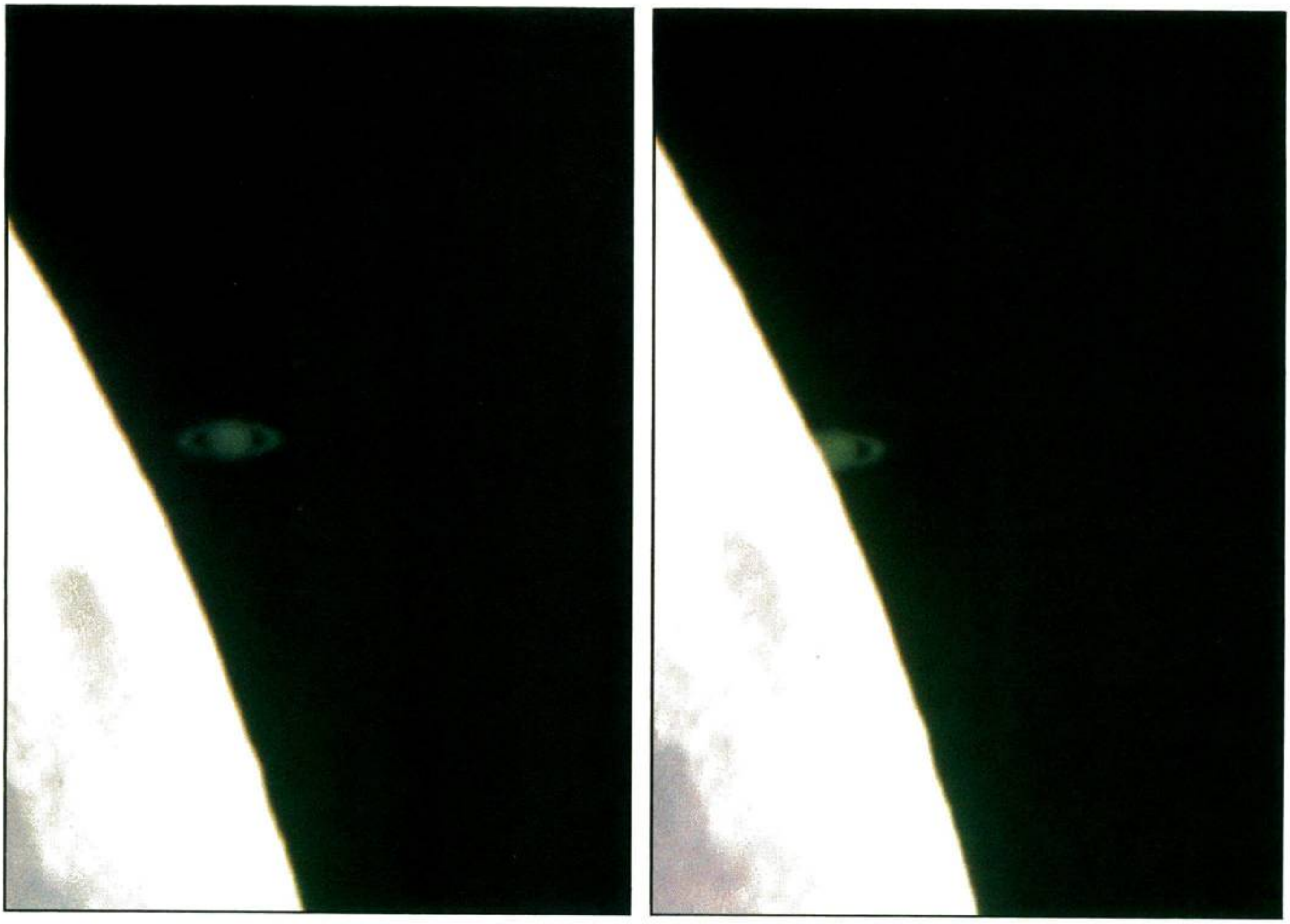
Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times in The Backyard Astronomer are UT unless otherwise noted. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska 9; and Hawaii, 10. For example, if an event is to happen at 03:00 hours UT on February 2, then EST for the event is 10 p.m., February 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m, March 4.

Moon Data

New Moon	April 1 at 12:10
First Quarter	April 9 at 4:51
Full Moon	April 15 at 19:11
Last Quarter	April 23 at 00:26
New Moon	May 1 at 3:45
First Quarter	May 8 at 11:50

Perigee: April 14 at 5:39.....360,542 km.
Apogee: April 26 at 6:47.....405,382 km.


LYR
18h
HER
12h
6h
AND
+40°
CYG
GEM
AUR
PER
CNC
ARI
+20°
PEG
LEO
9
6
PSC
BOO
30
VIR
TAU
AQL
12
1
ORI
OPH
HYA
26
AQR
15
19
CET
−20°
LIB
CAP
23
CMA
SCO
SGR
18h
12h
6h
−40



Astrophotographer Lee C. Coombs took a sequence of photos as the limb of the Moon approached Saturn for its occultation on December 29th last year. His instrument was a 10-inch f/5 Newtonian reflector, and he used eyepiece projection to enlarge the image. The exposures were 2 seconds on Ektachrome 400 film at an effective f/ratio of 90.

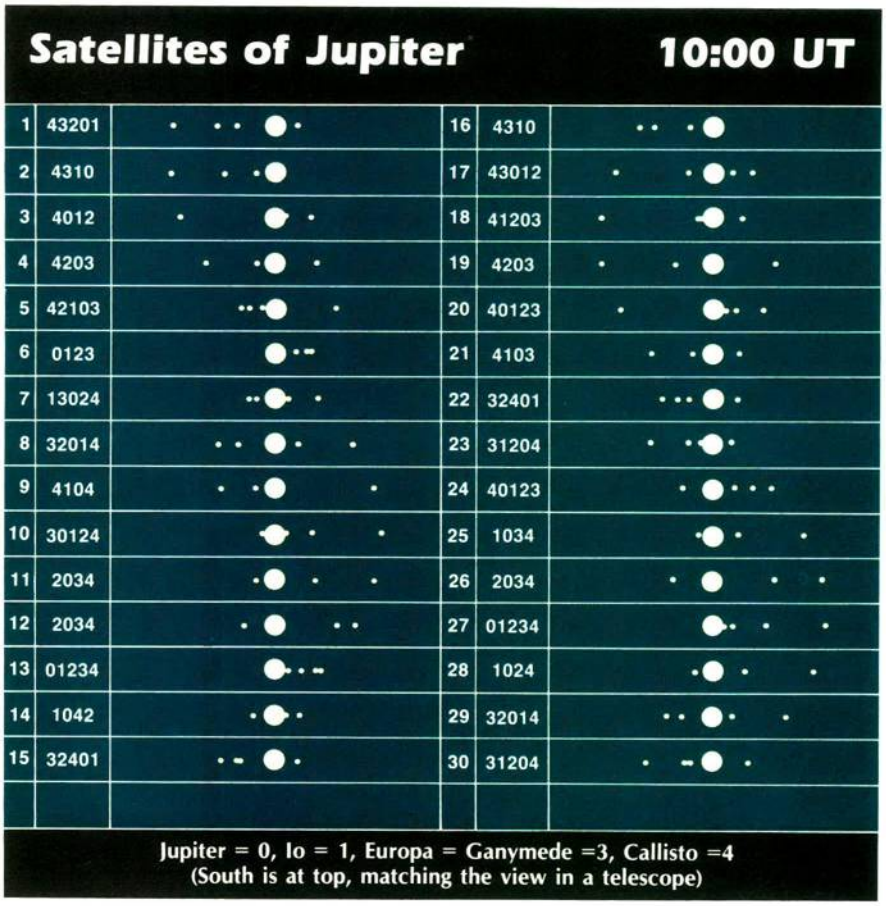
Mercury

On April 1st, Mercury will be almost at its peak elevation in the evening sky — see the diagram on page 83 last month. Greatest eastern elongation occurs on the 3rd; in your eyepiece the planet will be a tawny-white disk about 8″ of arc across.

Mercury's low elevation and consequent poor seeing conditions won't make for smooth or steady views, but you will still be able to follow the changes in its phases. It will grow larger (to about 10″) and become a slender crescent by the time it moves too close to the Sun to be seen — about April 15th.

Venus

Venus is now too near the Sun to be seen except in a daylit sky. If your scope has setting circles, you can observe Venus by offsetting from the Sun. How? First, use the coordinates tabulated on the opposite page to find out where Venus is relative to the Sun. On April 15, for example, Venus is 0h 59m west and 7° 39′ south of the Sun.



Satellites of Jupiter **10:00 UT**

1	43201	16	4310
2	4310	17	43012
3	4012	18	41203
4	4203	19	4203
5	42103	20	40123
6	0123	21	4103
7	13024	22	32401
8	32014	23	31204
9	4104	24	40123
10	30124	25	1034
11	2034	26	2034
12	2034	27	01234
13	01234	28	1024
14	1042	29	32014
15	32401	30	31204

Jupiter = 0, Io = 1, Europa = Ganymede =3, Callisto =4
(South is at top, matching the view in a telescope)

Right: Winner of the "Best Astro-Photo" Award is Steve Reed's photograph of the Moon near Last Quarter. Reed used an 8-inch SCT and an exposure of 1/60 second at f/10 on Fuji R-100 film. Left: M-51 is a bright spiral galaxy near the handle of the Big Dipper. Jack Newton took the photo with his 16-inch f/5 Newtonian and a 15-minute cold-camera exposure on Ektachrome 400.

Then wait for a clear morning with no haze and use eyepiece projection or an over-the-objective solar filter to center the scope on the Sun. *(Be careful!)* Offset the scope the necessary amount, remove the solar filter, and start looking for Venus with low power. Once you've found the planet's almost-"Full" disk, hold a red photo filter over your eyepiece to darken the blue sky and make Venus stand out better.

Mars

In mid-April, Mars rises about 9 p.m. local time, but won't be high enough to observe properly until an hour or so later. Mars is about a month before opposition and hasn't loomed so large in a telescope's eyepiece since 1976.

As the disk drawing on page 82 shows, we are looking at the planet's northern hemisphere — on about 10° north areographic latitude. On Mars, the Sun is some 7° higher than Earth in the sky, and the season is midsummer. (The martian autumnal equinox comes in the middle of our July.) Watch for occasional atmospheric changes — though it has only a fraction of the water vapor ours has, the martian atmosphere still has enough to feature clouds from time to time. Dust storms, too, are a possibility.

Asteroids

1 Ceres passed conjunction on March 22nd, and it is still too close to the Sun to be seen this month.

2 Pallas (magnitude 10.4) lies in southern Pegasus. Its positions:

10th: 22h 14m 24s, +5° 23.2′
20th: 22h 24m 53s, +6° 12.5′

Pallas rises around 3:30 local time on the 15th.

3 Juno (9.9) spends most of April moving eastward in Orion. Its positions:

10th: 4h 53m 45s, +12° 10.4′
20th: 5h 14m 56s, +13° 11.6′

Juno sets about 10 p.m. local time at mid-month.

4 Vesta (8.3) is traversing the Milky Way in Taurus and Gemini. On the night of April 23-24, Vesta will be passing through the open star cluster M-35 — a challenging and exciting event to observe. The brightest cluster members are about 7.6 magnitude; Vesta will be nearly a magnitude fainter. Its positions:

10th: 5h 46m 48s, +23° 53.1′
20th: 6h 1m 52s, +24° 9.4′

Vesta sets around 12:30 a.m. local time on April 15th.

For convenience in plotting their positions on a star atlas, all asteroid coordinates are for the epoch 2000.0.

Jupiter

Rising after midnight until the end of April, Jupiter's −2.3 magnitude gleam will far outshine the stars of Sagittarius, its "host" constellation this year. As detailed in Eye on the Sky, Jupiter will pass 6′ of arc north of fifth-magnitude Nu^1 (ν^1) Sagittarii at 12:10 UT on April 8th and 2.5′ north of Nu^2 (ν^2) at 4:41 UT on the 12th.

Jupiter also makes a fine sight in itself. As you observe the Great Red Spot, also keep an eye out for small white spots and festoons that appear in the equatorial belts. You'll need medium powers at least — 25x per inch of aperture or more — and good seeing to observe them, but they come and go over many weeks and present a more dynamic appearance than the Red Spot does.

Saturn

Saturn is approaching opposition (May 3rd), and can be seen rising in the east among the stars of Libra not too long after sundown. Telescopically it is a fine sight — perhaps the prettiest in the entire sky and one that will certainly make an indelible impression on any non-astronomer friends you show it to.

Uranus

Just barely visible to the naked eye at magnitude 5.5, Uranus displays a small (3.8″), luminous-appearing, grey-green disk in your telescope's eyepiece. Although it has five known moons, none is brighter than about 14th magnitude — territory for 8-inch or bigger scopes to explore.

Neptune

About the same size as Uranus, Neptune is 1.6 times farther away and thus appears smaller (2.2″) and dimmer. Look for a 7.9 magnitude disk about a degree north and 5m of r.a. east of the Trifid Nebula (M-20) in Sagittarius.

Pluto

Pluto is at opposition, 28.870 AU (4.301 billion kilometers) distant, at 16h UT on the 20th — see Gazer's Gazette on page 35.

Meteors

This month's chief meteor shower is the Lyrid, which reaches peak activity around 19h UT on April 21st. The Lyrids are medium-swift and bright; they also tend to leave streaks. There will probably be only some 10 to 20 per hour (the shower is highly variable in strength), and in any case, this year, the Moon — less than two days before Last Quarter — will come up and light the after-midnight sky.

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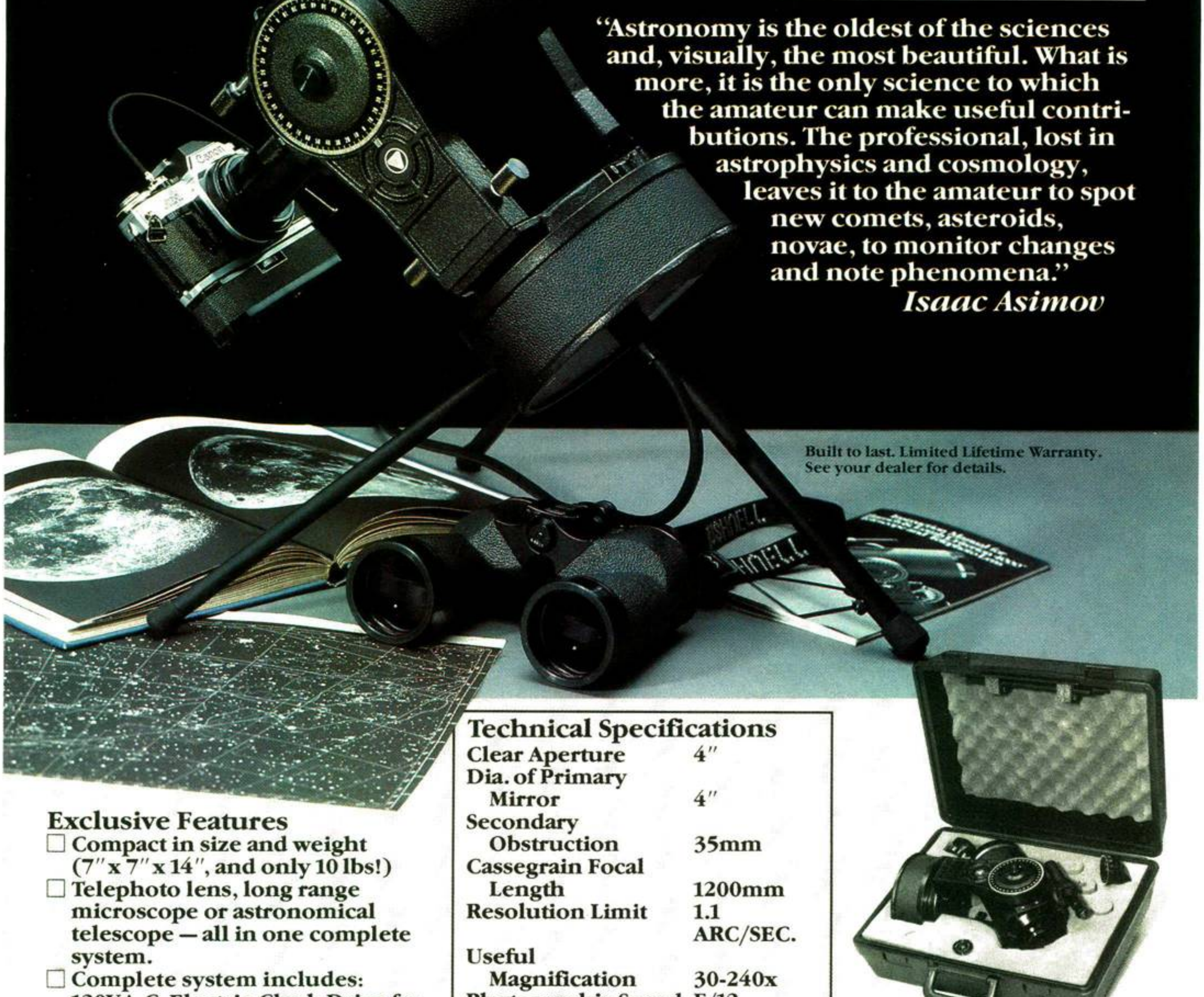

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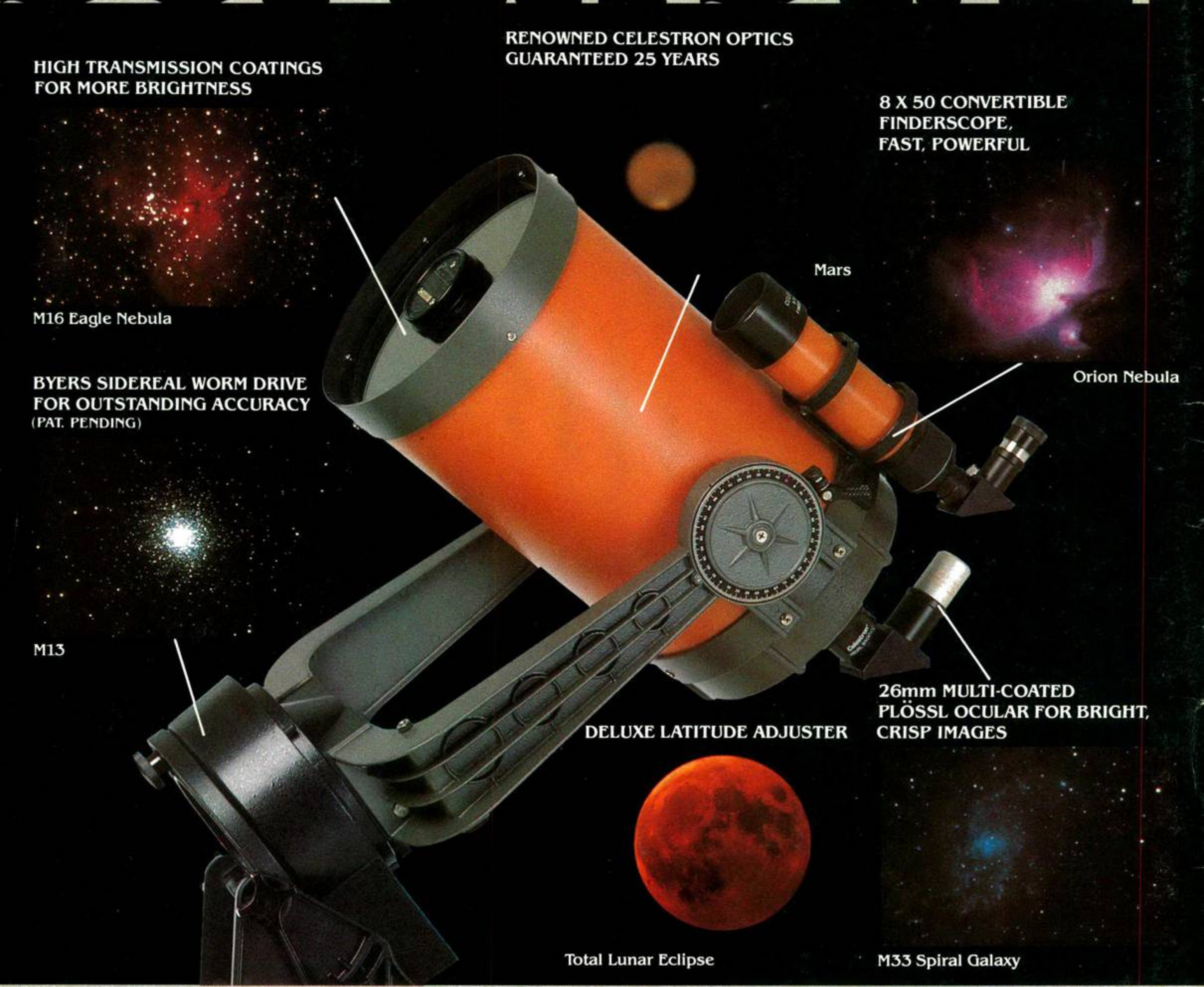
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